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October 2006

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Observing, telescopes, origin and fate of the cosmos

SPECIAL ISSUE

New search for extrasolar planets

The latest discoveries look more and more like Earth

Where are other civilizations hiding? p. 58

The forgotten man of cosmic inflation p. 64

Most of the 200 known planets beyond our solar system are gas giants, but smaller, rocky worlds have begun to turn up. Astronomers now hope to find earthlike planets within the next decade.

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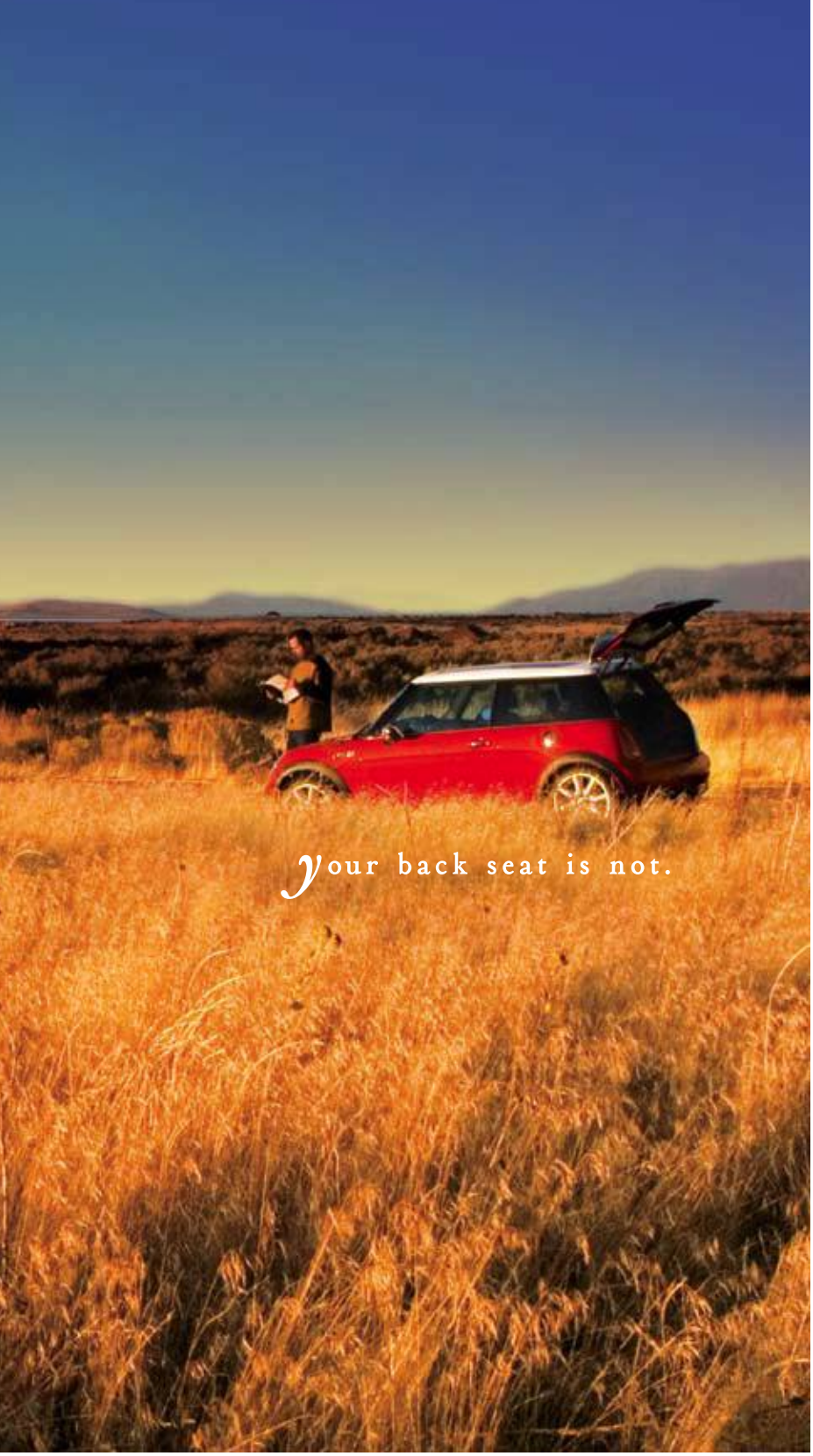

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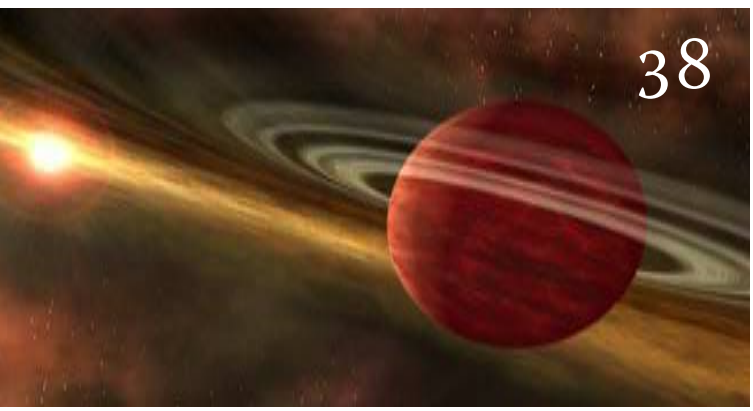

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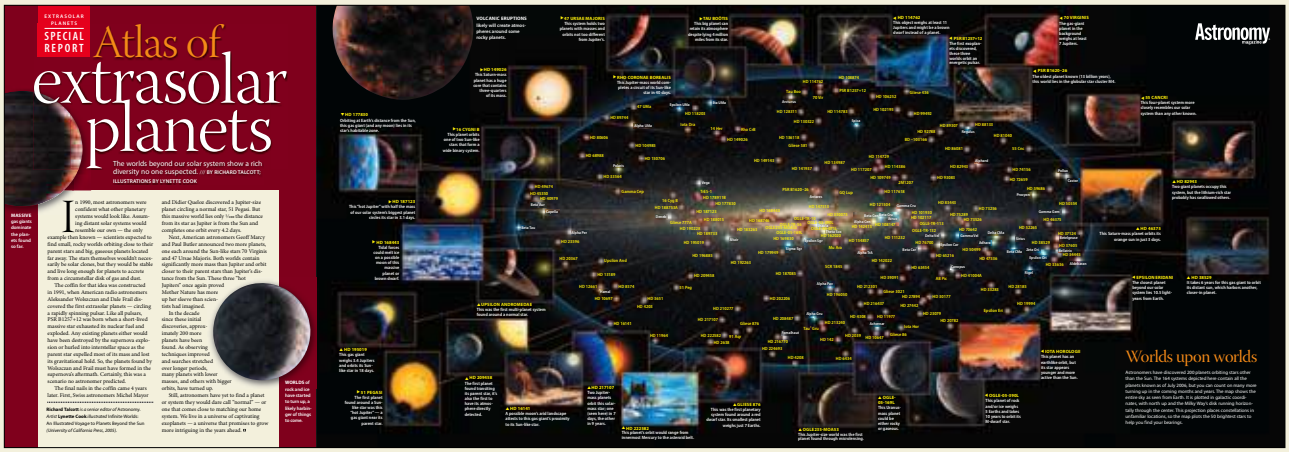
EXTRASOLAR PLANETS
SPECIAL REPORT
Atlas of extrasolar planets
The worlds beyond our solar system show a rich diversity no one suspected. // BY RICHARD TALCOTT; ILLUSTRATIONS BY LYNETTE COOK
Astronomy
Worlds upon worlds

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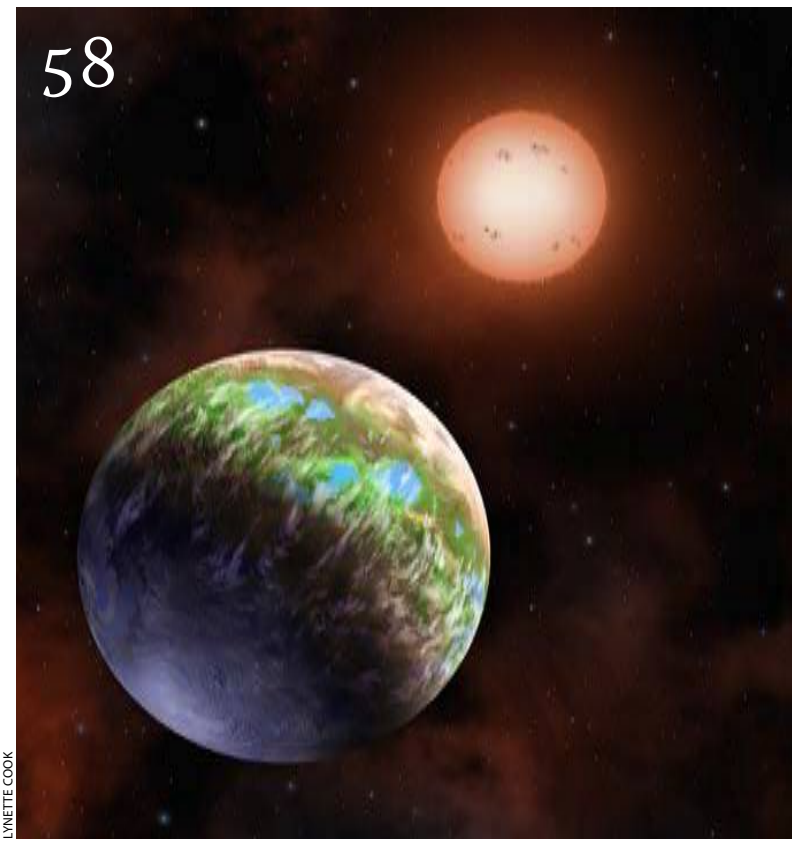

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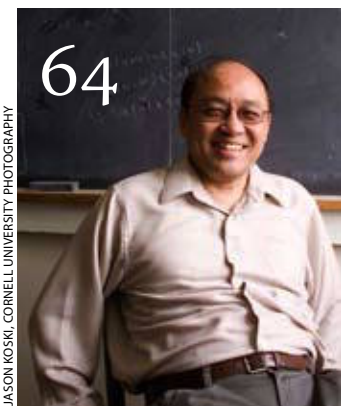

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JAMES R. FOSTER

BY DAVID J. EICHER

The extrasolar planets special issue

One question drives more people to

ponder the universe than any other: Are we alone? Before we get a grip on how much life may exist in the universe, however, astronomers need to sort out the potential places that could host it. The pace of extrasolar-planet discoveries — finding planets orbiting stars other than our own — has accelerated during the past decade.

Since the first exoplanet discovery, in 1995, astronomers have cataloged more than 200 additional planets in greater than 160 planetary systems. Future spacecraft missions will target exoplanets, so astronomers hope to find more massive gaseous planets and home in on smaller, rockier planets that might resemble Earth.

In "The new search for distant planets" (page 30), astronomer Geoffrey W. Marcy of the University of California, Berkeley, describes the state of exoplanet discoveries. Marcy is a preeminent authority for this exclusive article: His team has uncovered more exoplanets than any other group. Marcy forecasts a possible outcome of where exoplanet research is taking science.

The step of finding potential habitats for other civilizations is a startling moment in astronomical history, and, as Marcy reminds us, the indicators of biological activity on these planets may be seen from afar.

"Perhaps, in our lifetimes," Marcy advises, "we may know we are not alone."

Okay, so we know these big exoplanets are out there. How does the universe create them? Theoretician Alan P. Boss' "How do you make a giant exoplanet?" (page 38) explores the question of origins. Boss, a researcher at the Carnegie Institution of Washington, presents the theoretical ideas about how big planets form and matches them with current discoveries to provide an intriguing overview of what we know.

Oddly enough, not all the giant planets in the Milky Way orbit stars. Free-floating planets unbound to any star, in fact, could be the most plentiful objects in our galaxy. Astronomer María Rosa Zapatero Osorio explores this intriguing possibility in "Planets without suns" (page 44). Osorio, based at the Laboratory for Space Astrophysics and Theoretical Physics at Villafranca del Castillo in Spain, outlines the evidence for unbound planets roaming the galaxy and what they mean to future exoplanet research.

Those most special planets — the small, rocky ones that could host life — mean the most to astronomers. In "Where is life hiding?" (page 58), astronomer Margaret Turnbull of the Carnegie Institution of Washington describes the search for life on other planets. The astonishing possibilities will keep astronomers focused on future exploration programs.

The exceptional final piece of this great package is our foldout poster, "Atlas of extrasolar planets," featuring the artwork of celebrated San Francisco illustrator Lynette Cook. It's a project conceived and executed by Senior Editor Rich Talcott and Associate Editor Frank Reddy. This keepsake plots the positions on the sky of every known exoplanet system and is chock full of amazing information about these other worlds we are just now coming to know.

Yours truly,

David J. Eicher
Editor

Astronomy

Volume 34, Number 10

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Death's dramatic debris

Nearly 1,000 years ago, on July 4, 1054, Japanese and Chinese astronomers recorded a new star in Taurus. Little did they know, this suddenly brilliant object was the cataclysmic demise of an old star — a supernova. Today, the hydrogen-rich remains of the exploded star span 6 light-years. The wispy filaments reminded 19th-century Irish astronomer Lord Rosse of a crab, and the name stuck. The Crab Nebula (M1) is powered by the exploded star's collapsed core — a neutron star spinning 30 times a second that energizes both the stellar debris and electrons trapped in the star's powerful magnetic field.

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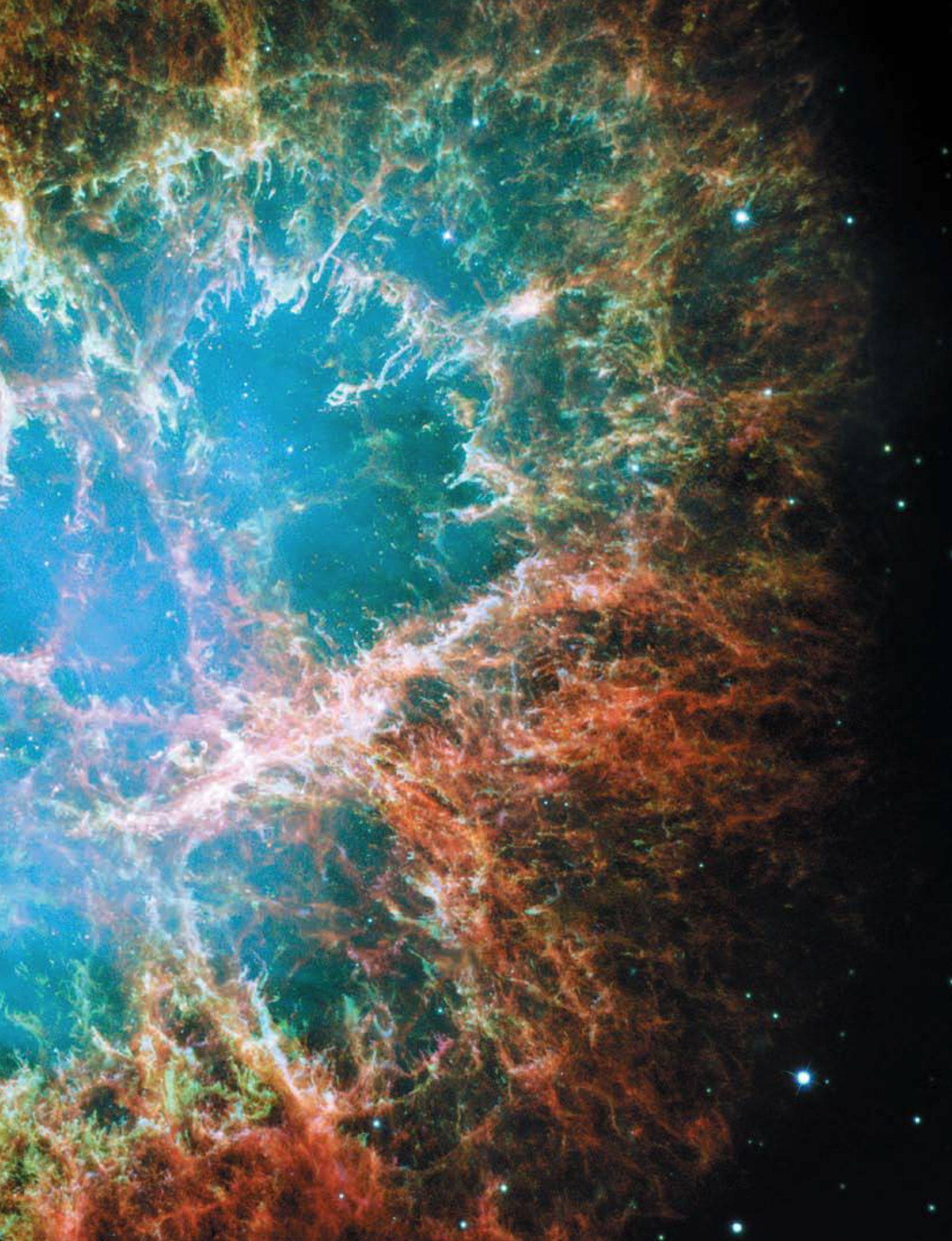

Keep it simple, please

Sometimes I laugh at the arrogance of some members of the science community. Do they really think decisions they make — like decreeing certain objects "planets" — somehow affect the balance of power in the universe? We are such small specks of dust in space, and yet we think the whole universe revolves around us.

Let's assign names to discovered objects and later decide their status. It's a lot easier to talk about Sedna, Tempel 1, and Planet X during public observing sessions than it is to remember 2003 UB_{313}. **— BRIAN MAPLE,** CERRO GORDO, ILLINOIS

No proof for dark energy

How could you publish an article like James Trefil's "Where is the universe heading?" (July 2006). Personally, I doubt the existence of dark energy. I find the idea of an unproven repulsive force repulsive! I suspect cosmic dust dims distant supernovae and makes cosmologists think the dying stars are farther away than they would be without dark energy. **— TOM WEIL,** WELLESLEY, MASSACHUSETTS

The astronomers who investigated SN 1997ff, which remains the most distant observed to date at a redshift of 1.7, looked hard at the dust issue. The main problem is dust in galaxies, but when that's estimated, the strange result remains. Future studies in multiple wavelengths will attempt to narrow down this source of error. **— FRANCIS REDDY,** ASSOCIATE EDITOR

Correction

I'd like to contribute a correction to Ray Villard's "Are Pluto and Earth two of a kind?" (June 2006). Villard says the Earth-Moon system captured Apollo 12's third-stage rocket booster after it launched the capsule and lander toward the Moon. He adds, "Scientists expect it eventually will crash into the Moon."

Most likely, the spent booster will reenter Earth's atmosphere and burn up.

Villard also implies the booster is still in Earth orbit. In fact, the booster was ejected into solar orbit after orbiting Earth for a few months. Not until the early 2030s will it orbit Earth again, and then only for a short time. **— RICHARD KOWALSKI,** LUNAR AND PLANETARY LABORATORY, UNIVERSITY OF ARIZONA, TUCSON

We welcome your comments. Send letters to Astronomy *Letters, P. O. Box 1612, Waukesha, WI 53187; e-mail to letters@astronomy.com. Please include your name, city, state, and country. Letters may be edited for space and clarity.*

THE STARS were important to the ancient Egyptians. In this rock carving, a bright star guides a man in a boat navigating the Wadi Hammamat River. TOBY WILKINSON

Observe like an Egyptian

"Stargazing in ancient Egypt" (June 2006) was fascinating. For those interested in reading more about astronomy in ancient Egypt, I recommend Peter Tompkins' *Secrets of the Great Pyramids*. He details the ancient Egyptians' astronomy knowledge and how they used the great pyramids for stargazing. Tompkins also explains that the Egyptians knew about precession of equinoxes, created star maps, and accurately calculated Earth's circumference. **— BOB CRANE,** GILROY, CALIFORNIA

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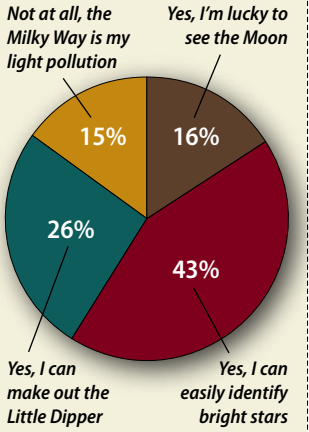
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The MAXSCOPE 40 Telescope with BF10 – New Low Price – $1699.

LOSMANDY

New Gemini goto in stock
G11 Mount with dual axis drive
GM-8 mount, dual axis drive

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MEADE DS 2130 includes Autostar and tripod refurbished $199.00

MEADE ETX-90 COMPLETE WITH 884 TRIPOD AND ELECTRONIC EYEPIECE $299.00

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We've been helping people choose the right telescope since 1979. We have the experience (a staff total of over 150 years of experience using and selling telescopes) to help *you* pick the telescope that fits your needs (and your budget). And, with our seven-figure inventory, we can usually ship you the right scope, right away, from the hundreds of scopes we stock.

We started ***astronomics*** over 27 years ago because we loved astronomy,

New 21st century Celestron go-to starts at only $599.

The new **Celestron NexStar SE Series** go-to scopes have all the optical performance and up-to-the-minute features you've come to expect from Celestron. And each is priced well below similar aperture competitive scopes.

The SE Series puts the bright images of Celestron's best Starbright XLT multicoated optics on sleek single fork arm go-to mounts. Each lightweight optical tube – finished in Celestron's vintage orange and black paint scheme – can be taken off its mount in seconds without tools and used on a photo tripod as a spotting scope or telephoto lens.

The convenient NexStar go-to computer hand control has no-guesswork *SkyAlign* technology. You don't need to level your scope, point it north, or memorize star charts to use a NexStar SE.

Simply point your scope at any three bright stars (or two stars and a planet or the Moon) and your scope automatically finds and tracks for you any of the up to 45,000 celestial wonders in its memory. Use the computer hand control mounted in the fork arm, as shown to the left, or hold it in your hand on the end of its coiled cord.

Red dot finder, Plössl eyepiece, star diagonal, tripod – these 21st century go-to telescopes have it all, and they are all yours for less than the cost of similar Celestrons from 1984 that didn't even have a computer or multicoatings!

The NexStar SE Series telescopes available from our stock include:

NexStar 4 SE, 4" Maksutov ..... **$599**^{00}
NexStar 5 SE, 5" Schmidt-Cassegrain ... **799**^{00}
NexStar 6 SE, 6" Schmidt-Cassegrain ... **999**^{00}
NexStar 8 SE, 8" Schmidt-Cassegrain . **1399**^{00}

Waiting for Hubble to land in your back yard?

You don't have to wait for the Hubble Space Telescope to fall out of orbit to have similar optics land in *your* back yard.

Meade LX200R scopes put f/10 modified Ritchey-Chrétien optics, similar to those in the Hubble, into Meade LX200GPS bodies for stellar astronomy at down to earth prices.

8" to14" LX200R go-to GPS scopes usually ship from our stock, saving you time over non-stocking dealers who have to order them from Meade. And if you live in California, we save you the sales tax on them, too.

Here are the *freight-paid* prices on the LX200R scopes that we ship from our stock:

8" **LX200R** ..... **$2499**^{00}
8" **LX200R,** with UHTC optics ..... **2674**^{00}
10" **LX200R** ..... **3399**^{00}
10" **LX200R,** with UHTC optics ..... **3634**^{00}
12" **LX200R** ..... **4399**^{00}
12" **LX200R,** with UHTC optics ..... **4694**^{00}
14" **LX200R** ..... **5999**^{00}
14" **LX200R,** with UHTC optics ..... **6349**^{00}

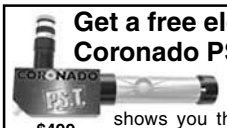
Because of their weight, these 16" LX200R scopes ship to you via truck from Meade.

16" **LX200R,** without mount, w/UHTC ... **11,529**^{00}
16" **LX200R,** tripod, w/UHTC ..... **12,494**^{00}
16" **LX200R,** altaz pier, w/UHTC ..... **12,524**^{00}
16" **LX200R,** eq pier, w/UHTC ..... **12,779**^{00}

12 volt power to the people for only $59^{95}!

You can recharge a **Celestron Power Tank** battery many times, saving you the cost of buying flashlight batteries every few weeks to power your scope. A 7 amp hour Power Tank is only **$59.95**.

Get a free electronic eyepiece with the $499 Coronado PST solar telescope.



Coronado's solar scope shows you the constantly changing drama of solar flares and prominences leaping off the Sun. At only $499, it's a world-class value.

The **Coronado PST** (Personal Solar Telescope) doesn't just show you sunspots, like an ordinary solar filter. It shows you the violent face of the living Sun. It includes a 60mm refractor, built-in sub-Ångstrom solar filter, a safe Sun finder, and a 25mm eyepiece.

And now, while quantities last, buy a Coronado PST at its regular price, and you get a Meade electronic eyepiece for free! The $149 list price electronic eyepiece lets you put those fascinating monochrome PST solar images on a TV screen for all to see.

The only thing better than getting a TeleVue is getting your TeleVue right away.

You rarely have to wait for your TeleVue from ***astronomics***, *since we keep a six-figure TeleVue inventory in stock.* Here are a few of the basic TeleVue refractors we stock.

TV-60, 2.4" f/6 apo ..... **$825**^{00}
TV-76, 3" f/6.3 apo ..... **1320**^{00}
TV-85, 3.35" f/7 apo ..... **1750**^{00}
TV-102, 4" f/8.6 apo ..... **2250**^{00}

And the new photo/visual *imaging system* refractors are in stock in limited supply. They include a larger non-vignetting focuser, Focusmate, photo accessory adapter, carrying case, and more.

TV-60is, 2.4" f/6 apo ..... **$1695**^{00}
TV-102iis, 4" f/8.6 apo ..... **2985**^{00}
NP-101is, 4" f/5.4 Petzval apo ... **3985**^{00}
NP-127is, 5" f/5.2 Petzval apo ... **6985**^{00}

Need a TeleVue eyepiece or accessory? We keep all of them in stock, too.

Celestron NexImage captures the solar system for $99.

The $99 **Celestron NexImage** CCD camera takes high power full color images of the Moon and planets with any telescope. It sends them to your computer to view live or print out later. The full color CCD imaging chip in the NexImage has a big 640 x 480 array of 5.4 micron pixels for sharp and clear high-resolution images.

For wider lunar panoramas, the optional $24.50 NexImage Reducer Lens doubles the camera's field of view.

Get a free electronic eyepiece with a Meade ETX.

While quantities last, buy a **Meade ETX Maksutov-Cassegrain** go-to and get a *free* Meade electronic eyepiece!

The $149 list monochrome electronic eyepiece lets you record close-up lunar and planetary images on a camcorder to view later or you can put them on a TV screen for all to see in real time. It's great for viewing with family and friends.

Meade ETX go-to scopes start at $599 and make it easy to find your way around the sky. Once you tell it where you are on earth, the date, and the time, your scope moves by itself to two alignment stars. Make sure the scope's finder is centered on those stars. Then tell your ETX which of the more than 30,000 objects in its memory you want to see, and your scope takes you to see that object *automatically.*

Each ETX comes with all you need to start observing – full length tripod, finder, 26mm Super Plössl eyepiece, and more.

And now, while quantities last, that "more" also includes a very useful free Meade electronic eyepiece!

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I have been surfing the last couple of nights looking for telescope eyepieces and accessories in general and have finally hit upon your site. I felt I must write to you to tell you how much I like your website. It is a wealth of information and well organized. The general background information is balanced (as in not overly biased toward the specifications of the products you offer) and extremely informative and helpful. The product information is very complete, more so than the combined offerings of many other websites.

Customer Quote of the Month #175

Want a 6 year-old to move your telescope?

Well, maybe *not* a good idea. But the 10" pneumatic tires, pivoting front wheel, and pull handle of the **ScopeBuggy** work so well that one friend's 6 year-old moves his 14" SCT all by herself.

TeleVue and Vixen combine for premium grab-and-go.

When the sudden urge to observe hits you, don't settle for second-best optics. Enjoy premium TeleVue apochromatic optics on a convenient Vixen "pick up in one hand and go" Porta altazimuth mount and save $110 over the cost of buying the components separately.

Choose from a 60, 76, or 85mm TeleVue refractor with superb apo (color-free) optics on an adjustable height Vixen mount with 360° slow motion controls. Even the biggest system weighs only 20 pounds, so they're easy to pick up in one hand and take anywhere – around the world or just out to your back yard for a quick peek.

Here are the TeleVue refractor/Vixen Porta mount packages that we stock.

TV-60, 2.4" f/6 apo, black ..... **$1165**^{00}
TV-76, 3" f/6.3 apo, ivory or green ... **2065**^{00}
TV-85, 3.35" f/7 apo, ivory or green . **2490**^{00}

Celestron *SkyAlign* go-to scopes start at a low $279.

You don't need to know the Pleiades from Polaris to find your way around the skies with a **Celestron SLT** go-to scope. With Celestron *SkyAlign* technology, just point your SLT at any three of the 50 brightest lights in the sky (3 stars, or 2 stars and a planet), and the SLT will find the planets and over 4,000 deep space objects for you *automatically.* A few anonymous points of light are all you need to find celestial wonders like a pro.

Celestron SLT no-guesswork go-to scopes are available in these sizes:

NexStar 60, 60mm refractor ..... **$279**^{00}
NexStar 80, 80mm refractor ..... **379**^{00}
NexStar 102, 102mm refractor ..... **479**^{00}
NexStar 114, 114mm reflector ..... **399**^{00}
NexStar 130, 130mm reflector ..... **439**^{00}

Each has *two* eyepieces, red dot finder, motor drives, stainless steel tripod, NexStar computer, software to control the scope from your computer, and more.

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not just as a business. Our sales may have grown over a thousand-fold since that first year, but we're still the same family-owned, family-run, full-line telescope dealer we were in 1979. And we still love astronomy.

Astro-Tech refractors. Big performance. Little price.

Premium apochromatic (color-free) and achromatic optics no longer cost a king's ransom. Optically excellent compact fast focal ratio refractors, such as these from **Astro-Tech**, are affordable and practical. They mount on an ordinary camera tripod, as well as on an altazimuth or equatorial mount, so they're ideal to take to the backyard for spur-of-the-moment stargazing. They're also great for nature studies and as a convenient travel scope or vacation take-along.

We keep 14 different 66mm and 80mm grab-and-go Astro-Tech scopes in stock.

Left to right: **Astro-Tech** AT66ED, $329; AT80, $379; AT80ED, $529

Just take a look at these:

Astro-Tech AT-66ED apo: 66mm f/6 ED apo, Crayford rotating dual-speed focuser, eight tube colors, equatorial dovetail, hard case ..... **$329**^{00}

Astro-Tech AT-80: 80mm f/6 achromat, dual-speed rotating Crayford focuser, choice of four tube colors, tripod mounting shoe, soft case ..... **$379**^{00}

Astro-Tech AT-80ED apo: 80mm f/6.9 ED apo, Crayford rotating dual-speed focuser, choice of two colors, equatorial dovetail, hard case ... **$529**^{00}

Outer space is infinite. Your car's back seat is not.

Meade LightBridge Dobsonians use a truss-tube design that lets even the big 12" models break down into a few small packages that easily fit into a compact car. One person can transport even the largest Meade LightBridge to a dark sky site and set it up on their own.

Meade 10" f/5 standard LightBridge **$649**

All Meade LightBridge Dobs have a 2" machined aluminum Crayford-style focuser with a 1.25" eyepiece adapter. The battery-operated fan on the metal primary mirror cell assures fast cooling of the diffraction-limited BK7 optical glass mirror. No tools are needed to assemble and break down each scope in the field.

Standard models have a 1.25" 26mm Super Plössl eyepiece, a red dot finder, and Teflon bearings. Deluxe models have a 2" 26mm 70° field QX eyepiece, an illuminated finder with four different reticle patterns, and roller bearings for smooth hitch-free motion at the touch of a finger.

The prices below include the shipping from the Meade factory.

8" f/6 standard LightBridge ..... **$469**^{00}
8" f/6 deluxe LightBridge ..... **569**^{00}
10" f/5 standard LightBridge ..... **649**^{00}
10" f/5 deluxe LightBridge ..... **749**^{00}
12" f/5 standard LightBridge ..... **949**^{00}
12" f/5 deluxe LightBridge ..... **1049**^{00}

Accessories for Meade LightBridge Dobs.

Astrozap light shroud for LightBridge **$79**

Meade LightBridge Dobs are great performers as they come, but a few accessories make them even better.

An **Astrozap** light shroud at $79 keeps the mirrors from dewing up, improves image contrast, and keeps butter-fingered observers from dropping an eyepiece on your mirror.

A $45 set of **Bob's Knobs** makes it easy to collimate both mirrors of a 10" or 12" LightBridge without needing the two small screwdrivers usually required.

GPS tells a Meade LX90 where to go.

Meade 8" LX90-GPS **$1899** *freight paid*

Meade LX90 8", 10", and 12" go-to Schmidt-Cassegrain telescopes with GPS (Global Positioning System) technology make it easy to find your way around the sky.

You don't have to tell an LX90 where or when you are on earth in order to find any of the more than 30,000 celestial wonders in its memory. Its GPS receiver gets that information from a net of 24 Earth-orbiting satellites, then moves to two alignment stars – *all automatically!* Simply check that your LX90's red dot finder is centered on those two stars (you also get an 8 x 50mm finder), then start enjoying computerized go-to observing. An LX90 makes astronomy that easy!

We keep them in stock, so we can ship faster than dealers who have to order them from Meade (and if you live in California, we save you the sales tax, too).

Here are the *freight-paid* prices on the LX90 scopes that we ship from our stock:

8" LX90-GPS ..... **1899**^{00}
8" LX90-GPS, with UHTC optics ..... **2074**^{00}
10" LX90-GPS ..... **2499**^{00}
10" LX90-GPS, with UHTC optics ..... **2734**^{00}
12" LX90-GPS ..... **2999**^{00}
12" LX90-GPS, with UHTC optics ..... **3294**^{00}

Not much money buys you a lot of Konus.

The low prices of **Konus** telescopes are downright amazing.

If you're not looking for go-to, but just want a good scope for casual observing, consider this optically nice 90mm (3.5") **Konusmotor-90** f/11 refractor. It has an equatorial mount with adjustable tripod, a 6 x 30mm finderscope, battery-powered motor drive so you can use it anywhere, and *two* 1.25" Plössl eyepieces.

$209

3.5" f/11 Konus refractor

We sell it by the dozens because it's a great value at $209. And there are other Konus motor drive scopes from $109 to $799.

astronomics. No hard sell. No guesswork. Just honest advice, the time to make sure you get the right telescope and accessories, and a good price. Call us toll free at (800) 422-7876 and find out for yourself.

Reader's Digest calls the Celestron SkyScout one of the "Best of America."

$399 freight paid

The May issue of *Reader's Digest Magazine* named the 100 best things in America, and the **Celestron SkyScout** was named the "Best Star Finder." This award-winning handheld non-magnifying GPS-based personal planetarium identifies or locates more than 6,000 celestial objects visible to the unaided eye, then tells you their facts and history. You can use the SkyScout to learn the legends, myths, and sights of the sky.

There's a scrolling 5-line text and graphics display. Supplied earbuds let you hear the text so you don't have to look away from the sky to read it. Optional speakers let others hear, too.

The SkyScout transforms the night sky into a planetarium for stargazers, families, and students. It makes identifying what's in the sky easier than ever before.

All no-guesswork Celestron *GPS* SCTs are in stock.

Celestron 8" f/10 CPC800 **$1899**

It's easy to find your way around the sky with a **Celestron CPC**. Just point it at any three bright lights in the sky (3 stars, or 2 stars and a planet or the Moon), and the CPC will find over 45,000 deep space objects for you at the touch of a button.

You don't have to enter your time or location or memorize a star chart to use a CPC. Its built-in GPS system and a few anonymous lights in the sky are all you need.

Celestron's CPC Schmidt-Cassegrains come with all the features you need to start go-to observing immediately.

8" **CPC800**, Starbright multicoatings ... **$1899**^{00}
8" **CPC800X**, XLT multicoatings ..... **1999**^{00}
9¼" **CPC925**, Starbright multicoatings .. **2349**^{00}
9¼" **CPC925X**, XLT multicoatings ..... **2499**^{00}
11" **CPC1100**, Starbright multicoatings . **2599**^{00}
11" **CPC1100X**, XLT multicoatings ..... **2799**^{00}

Get a $399 Deep Sky Imager Pro CCD camera for $129 when you buy a Meade telescope.

The **Meade Deep Sky Imager Pro** CCD camera sells for $399. But now, while supplies last, you can get the DSI Pro for only $129 when you buy a Meade LXD75, LX90, LX200, or RCX400 telescope!

The monochrome DSI Pro is loaded with features like NASA-developed "Drizzle" software that sharpens the resolution and quadruples the size of your LX90, LX200, or RCX400 deep space photos. And the filter set for tricolor imaging, normally $199, is only $99 if bought with camera and scope.

The DSI Pro opens up a whole new way to observe with a Meade telescope. Best of all, you save a total of $370 on the DSI Pro and color filter set when you buy them along with your LXD75, LX90, LX200, or RCX400.

A Telegizmos protects your scope day and night.

A **Telegizmos** scope cover protects your telescope from sun and dew. NASA-developed to insulate spacecraft, these aluminized covers are strong, light, and more durable than Mylar. Prices start at only $29.

Get a $158^{95} value accessory kit for $49 when you buy a Celestron telescope.

This **Celestron Telescope Accessory Kit** normally sells for $99 and is worth every penny. But now, through the end of the year, you get this nine-piece kit for only $49 when you buy any Celestron telescope priced at $199 and up!

The kit is full of useful accessories. You get 12.5mm and 32mm 1.25" Plössl eyepieces, a 1.25" 2x Barlow to double the power of all your eyepieces, four 1.25" filters for lunar and planetary observing (orange, blue, green, and neutral density), a no-battery flashlight that generates and stores power just by shaking it, all in a fitted aluminum-finish case – *and all for only $49!*

Astro-Tech *dielectric* diagonals start at only $69^{95}.

Astro-Tech dielectric star diagonals increase light transmission *and* improve contrast and detail compared to the so-so prism diagonal supplied with most scopes.

**$139**^{95} **$69**^{95} **$149**^{95}

Each has 99% reflectivity *46-layer dielectric* mirror coatings on a 1/10th wave BK7 optical glass substrate, and non-marring brass compression ring eyepiece holder. The 2" diagonals also come with a 1.25" eyepiece adapter with a compression ring eyepiece holder at no extra charge.

The 2" diagonals are available with a standard 2" barrel to use in a refractor or with a threaded ring that connects to a Schmidt-Cassegrain rear cell.

Here are the top-quality **Astro-Tech** dielectric star diagonals that we stock:

1.25" dielectric **$69.95**
2" dielectric **139.95**
2" SCT dielectric **149.95**

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BY BOB BERMAN

Space-travel woes

Will humans colonize other worlds?

This science-fiction theme often seems like our inevitable destiny. Acting on it, NASA now has specific plans to return to the Moon, along with vague plans for Mars. But will it really happen? Many astronomers hate the whole thing.

Such astro-luminaries as Berkeley's Geoffrey Marcy and NASA's Fred Espenak bemoan cuts to science programs to make room for expensive manned missions.

As for the public, it lost interest in Apollo after the first Moon landing in 1969. Returning to the Moon may ignite the same media excitement as a seniors' Sudoku tournament. Will three future administrations get on board, knowing that voters won't care even if they slice Moon funding to match the government's budget for studying pelicans?

Mars, on the other hand, remains exciting. It probably has underground ice, which means water for astronauts. Solar panels could dissociate ice into hydrogen and oxygen fuel. Let's go!

Not so fast. There's a dark side here, too. We've had major hints that manned space travel might be a dangerous bummer.

"I found it extremely boring," assessed Wally Schirra after 11 days of commanding the first Apollo spacecraft. Well, he was sort of a crank, but what about the Russians who spent years in simulators and aboard Mir? They often got seriously depressed. True, they're Russians: Ever read a Russian novel? Nonetheless, they'd grow plants and then check them a half dozen times a day, lovingly and obsessively touching the only natural thing in their module.

"I suffered sadness and mental stress," said Anatoly Grigoriev after 438 days in space.

Vadim Gushin adds, "The plants helped us establish ties with Earth, with nature. This is the essence with which the human mind is based."

Duh! Of course! Humans evolved to hear rustling leaves and interface with wind and pollen, to be immersed in nature.

Isolate a person with bottled air, fluorescents, and plastics, and who knows what psychological damage must follow? Spending years away from Earth could drive astronauts loony.

But it's not just the mind. As results trickle in from the International Space Station and elsewhere, astrobiologists grow more concerned, not less, about the long-term consequences of space travel.

WE'VE HAD MAJOR hints that manned space travel might be a dangerous bummer.

In orbit, bone and muscle vanish at 1 percent per month, and some of this loss is irreversible. Hearts shrink in size, so cardiac capacity goes steadily downhill. Astronauts might look like they're happily at the gym up there, on the treadmill in their underwear, but it's hopeless: Space is just not good for you.

Things really get bad when you leave orbit and pass outside Earth's magnetosphere, the barrier against solar and cosmic radiation. Apollo astronauts all saw flashes like meteors cross their visual fields about once a minute, as heavy ions ripped through their brains. Their radiation exposure was not trivial, and, years later, Alan Shepard didn't deny that going to the Moon may have given him the leukemia that eventually killed him.

Things could have been worse. A coronal mass ejection blasted the Moon with charged particles just 1 month before the final Apollo 17 mission. Had the astronauts been on the surface — or in their capsule going or coming — they would have died.

Okay, so we build a shielded "safe room" on the Mars-bound craft. Problem is, the Red Planet has no magnetosphere. Gamma rays and X rays from distant supernovae rain down on the surface, along with those pesky charged particles from the Sun. The continuous ionizing background flux disqualifies that planet as a health spa.

High cancer risk aside, brain neurons will be destroyed continuously by the nonstop radiation. Biologists estimate that during a 2-year Mars mission, an astronaut may lose between 13 and 40 percent of her or his brain! Ouch! Even smart people can't afford that. It greatly exceeds the 5 percent annual neuron necrosis suffered by some Alzheimer's patients.

Once at the Red Planet, astronauts will have to fend for themselves: There'll be no ride home for at least 18 months after arrival, when Earth and Mars again align. You're on a place without breathable air. It's always freezing. Radiation is giving you a splitting headache. The pizza's terrible.

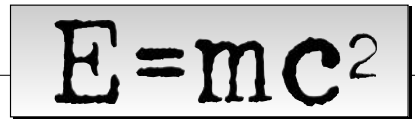
Still want to go?

Maybe nobody else will either.

Heroic astronauts are always willing to risk their lives for science. But except for those with serious credit-card debt, ordinary folks might not want to rush off-world if the hazards are too high.

Time will tell. But just in case Earth proves to be our only home, maybe we should take care of it.

EINSTEIN deciphered the puzzles of the universe for every scientist in the world. Isn't it about time someone deciphered them for you?



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Is time travel into the future possible? Yes—but if you don't like what you find, you can't come back! Does a single raisin contain enough energy to power New York City for a day? Absolutely! Do black holes and wormholes exist? Quite possibly! Is the universe governed by laws that strictly predict what will happen in the future, or by chance? In part, by chance. These and other consequences flow from relativity and quantum physics.

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Dr. Richard Wolfson (Ph.D., Dartmouth College) is Professor of Physics at Middlebury College in New England. Decades of teaching at Middlebury, with its strong emphasis on the humanities, have made him an expert at demonstrating the logic and significance of physics to students from many fields. His writings have appeared in *Scientific American*. He is author of *Physics for Scientists and Engineers*.

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Offer Good Through: November 4, 2006

BY GLENN CHAPLE

A dumbbell for you

Hey, everybody, I was joking! Last month, I suggested that the Dumbbell Nebula was named after me. Some readers believed the story — well, at least those who know me. Let me set the record straight. Any similarity between the nickname of a certain planetary nebula

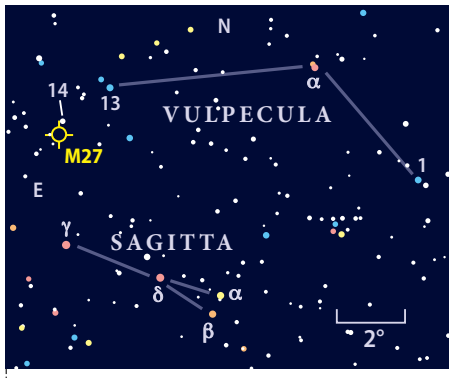
in the constellation Vulpecula and yours truly is purely coincidental.

Even though it wasn't named for me, the Dumbbell Nebula is one of my favorite deep-sky objects. Also known by the Messier designation **M27**, it's the brightest and easiest-to-observe of all planetary nebulae. Only the Ring Nebula (M57), which is smaller and fainter — but much easier to locate — attracts more attention.

Planetary nebulae are a particularly fascinating class of deep-space object. The death throes of an average-size star, like our Sun, create these cosmic puffballs. As the ailing star's core switches from hydrogen to helium fuel, it sheds its outer layers in an expanding shell of gas. The shell's spherical shape gives the typical planetary nebula its planet-like appearance.

Planetary nebulae fade away faster than the emission and reflection nebulae that give birth to stars. While the latter survive for millions of years, a planetary nebula's gases dissipate into the blackness of interstellar space after a few thousand years.

THE DUMBBELL NEBULA is a popular target for astroimagers. MIKE FULLER



DON'T LET trying to find the Dumbbell Nebula, M27, leave you dumbfounded. This finder chart can help you find the sometimes elusive, but always-impressive, target. *ASTRONOMY:* ROEN KELLY

Finding M27 can be a challenge even for the experienced skygazer. Its parent constellation, **Vulpecula** the Fox, contains no bright naked-eye stars. To find M27, trace a line from Gamma (γ) Lyrae through Beta (β) Cygni, and then extend it an equal distance beyond.

Or, if you can find the constellation **Sagitta**, you can take a more direct route to M27 by aiming toward Gamma Sagittae and then moving about 3° northward. Under a dark sky, binoculars and finder scopes will pick up M27 as a small smudge of light close to the star 14 Vulpeculae. A low-power eyepiece can sweep up M27 because of the nebula's relatively large size (8′ by 5′) and brightness (magnitude 7.3). Once you've found it, switch to higher power. The Dumbbell is a remarkable sight at magnifications of 100x or more.

M27 has delighted and mystified observers since Charles Messier discovered it in 1764. Small telescopes show it as a rectangle with rounded edges. Its dumbbell shape — also described as an hourglass, bow tie, or apple core — is visible in medium- to large-aperture instruments. Apertures of 10 inches or larger (6- to 8-inch scopes in dark-sky locales) will reveal faint, pointed nebulosities extending from the Dumbbell's long sides. With an Oxygen-III filter attached to an eyepiece to enhance subtle detail, my 13-inch Dobsonian turned the Dumbbell Nebula into the "Football Nebula."

Any planetary nebula's central star can be a challenge to see because it's a faint white dwarf immersed in nebulosity. I've glimpsed M27's central star in my 13-inch using a moderately high magnification (175x), and I suspect it can be viewed with an 8-inch scope under favorable conditions. If you have trouble seeing the central star, try averted vision. Here's a trick to see faint stars and nebulous detail: Concentrate your gaze to the side of your target. The light then falls on a more sensitive part of the retina, revealing detail not normally visible with a direct view.

What I find most fascinating about the Dumbbell is the 3-D illusion it presents when viewed through a telescope. The Dumbbell seems to hover in the foreground against the backdrop of Milky Way stars.

If you've never seen M27, put it on your observing list for the next clear, moonless night. If you've already notched it with your telescope, don't assume a "been there, done that" attitude. Like a fine painting, M27 shows something new each time you study it. This dumbbell will be giving the Dumbbell Nebula some serious attention during the months ahead. Why not join me?

Questions or comments? E-mail me at gchaple@hotmail.com. Next month: a look at the "Demon Star." Clear skies!

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BY PHIL HARRINGTON

Meet Mr. October

If you're a baseball fan, then you're

familiar with "Mr. October" — Hall-of-Famer Reggie Jackson, who played in the major leagues from 1967 to 1987. He earned the nickname for his heroics during many World Series games. With the 2006 fall classic around the corner,

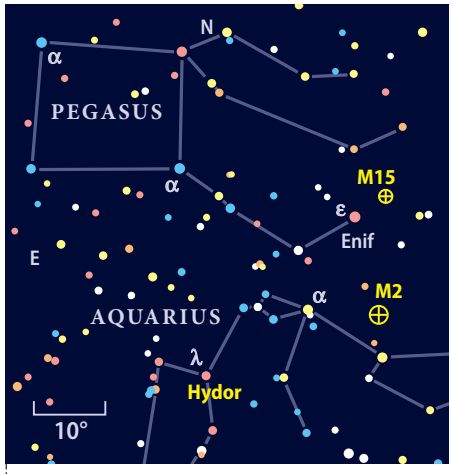
let's scout potential Mr. Octobers among the objects in this month's night sky, which holds two intriguing prospects: Perseus the Hero and Cepheus the King.

Perseus lies in the northeastern sky. In mythology, his bravery saved Princess Andromeda from certain death. Cepheus — Andromeda's father — stands high in the northern sky. The autumn Milky Way's faint stream immerses both constellations, which hold many binocular treats.

While these two figures boast impressive resumés, let's turn our attention toward an often-ignored Mr. October: **Aquarius** the Water-bearer. Greek mythology identifies Aquarius as Ganymede, Zeus' favorite water boy. According to legend, Zeus deified Ganymede as Aquarius, the god of rain. He was eventually raised into the sky as one of the 12 zodiacal constellations.

Light pollution often masks the constellation's faint outline. To begin your binocular tour of Aquarius, start at the Great Square of **Pegasus**. Draw an imaginary line diagonally from the Square's northeastern star, Alpheratz (Alpha [α] Andromedae), to Markab (Alpha Pegasi), at the southwest corner. Continue the line an equal distance farther southwest. There, you should find a Y-shape asterism made up of 4th- and 5th-magnitude stars known as Aquarius' water jar. All of the stars fit into most binocular fields of view. Add in the star Sadalmelik (Alpha Aquarii) to their west, and you can form a convincing arrowhead.

Follow the arrowhead's aim to the west about 1 binocular field, and you will come to a small, faint smudge of light — the globular cluster **M2** (NGC 7089). This megalopolis contains about 150,000 stars. Unfortunately, most binoculars don't have enough oomph to resolve M2 into anything more than a tiny celestial cotton ball. While most globulars look round, my 16x70s show M2 as slightly oblate.



AQUARIUS THE WATER-BEARER earns his status as Mr. October thanks to an outstanding roster of objects in this month's night sky. *ASTRONOMY:* ROEN KELLY

I enjoy comparing similar types of objects, and we have a great opportunity to do just that with M2. If you head about 2 binocular fields north, you'll zero in on another globular cluster, **M15** (NGC 7078), in Pegasus. M15 lies about 4°, or ½ a binocular field, northwest of the star Enif at the tip of Pegasus' nose. Look for a 6th-magnitude star just to the cluster's west. Together, they create an unusual "double star." It's easy to tell the globular from the star, because M15 will look noticeably fuzzy. Compare the two globulars. M15 will probably strike you as slightly smaller than M2, and maybe even brighter.

M15 was the first globular cluster found to contain a planetary nebula. In 1921, German astronomer Friedrich Kuster spotted the planetary, but he thought it was just a cluster star. The nebula's identity wasn't deduced until 1927, when Francis Pease studied M15 with the 100-inch Hooker reflector at Mount Wilson. We now know this nebula as Pease 1. Despite the fact that large telescopes can spot Pease 1 easily, it's a nice challenge object for binoculars.

Finally, head back to the water jar, and then move about 10° southeast to the star **Hydor** (Lambda [λ] Aquarii). A glance through binoculars shows Hydor radiating a red or orange glow. As a red giant star, Hydor measures about 100 times the diameter of our Sun.

Hydor almost lies on the ecliptic, so the Sun, Moon, and most planets will occasionally pass its way. As October opens, Uranus lies less than 1° southeast of Hydor. The 6th-magnitude planet's tiny green disk contrasts nicely with the red hue of the 4th-magnitude star, and the two create a colorful pairing through binoculars. As the month progresses, watch Uranus move to the star's west and complete a retrograde loop in the sky. If you have never seen Uranus, this is a great opportunity to do so.

Incidentally, Neptune lies to the west of Uranus, in Capricornus. Drop by this month's "online extra" for tips on finding the eighth planet through your binoculars.

Come back next month, and dress your best. We have an audience with the Queen. Till then, remember, when it comes to stargazing, two eyes are better than one!

ONLINE EXTRA Learn how to see Neptune with your binoculars at www.astronomy.com/toc.

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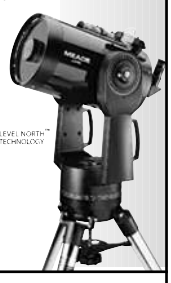

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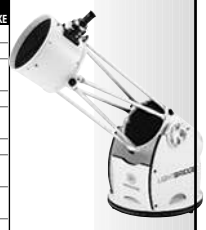

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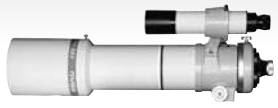

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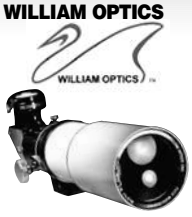

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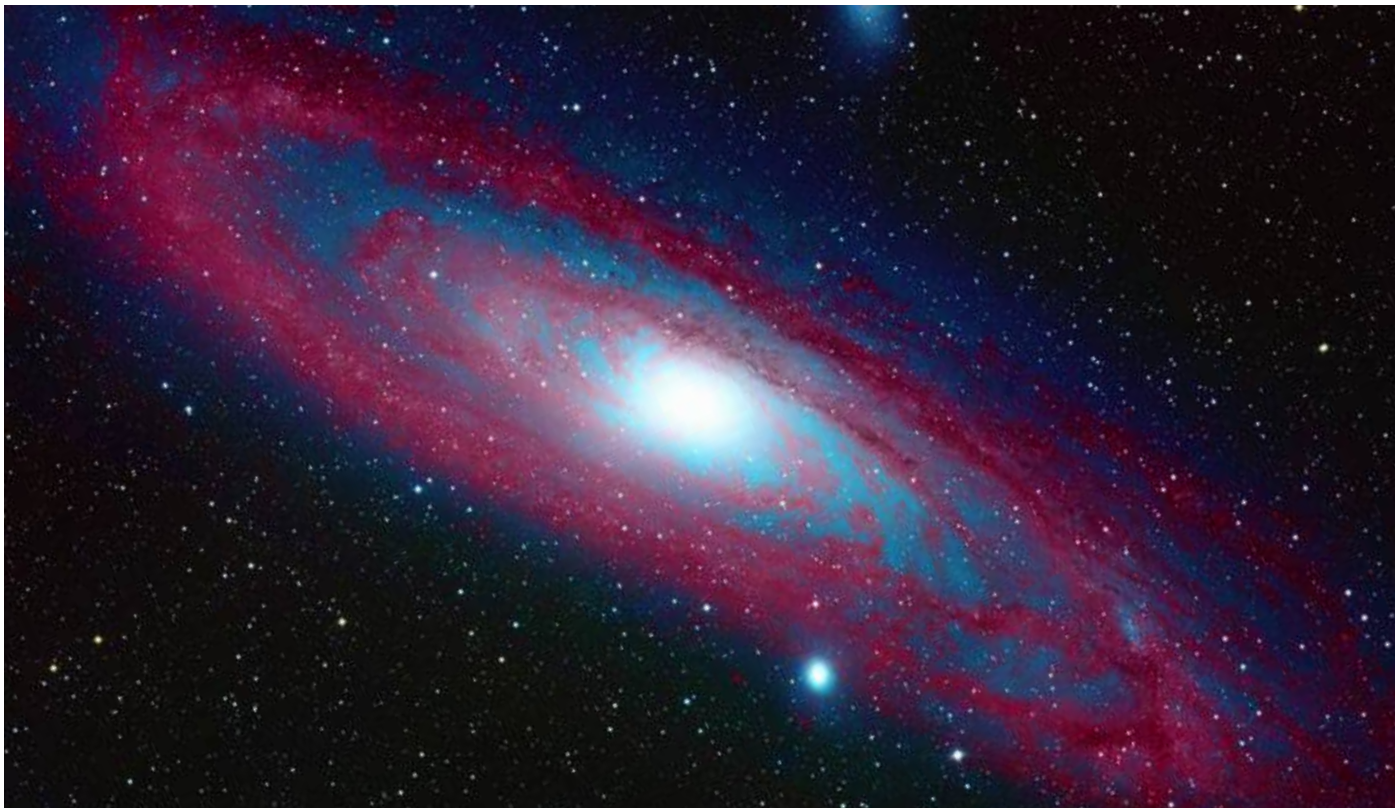

INFRARED: NASA/JPL/SSC-CALTECH; VISIBLE: NOAO/AURA/NSF

DUSTY GALAXY. The Andromeda Galaxy glows blue (stars) and red (dust) in this mosaic of more than 3,000 Spitzer Space Telescope images.

24 Australian mounds formed by ancient life

26 Is the Big Bang an encore?

28 Astro, Nextsat to test robotic docking

29 Antarctic ice may hide giant crater

Spitzer gives best view yet of dusty M31

A new Spitzer Space Telescope portrait of the Andromeda Galaxy (M31), the nearest spiral galaxy to our own Milky Way, gives astronomers their best view yet of the dusty spiral arms. The mosaic comprises some 3,000 individual images.

"What's really interesting about this view is the contrast between the galaxy's smooth, flat disk of old stars and its bumpy waves of dust heated by young stars," says Pauline Barmby of the Harvard-Smithsonian Center for Astrophysics in Massachusetts.

Barmby and her team used the Spitzer data to make vastly improved measurements of Andromeda's infrared brightness. In these wavelengths, the galaxy shines with the same energy as about 4 billion Suns. Astronomers estimate M31 hosts roughly 1 trillion stars, which jibes with estimates from other wavelengths. Astronomers estimate our Milky Way Galaxy holds some 200 billion stars.

Spitzer's camera sees more than the glow of M31's stars. At longer infrared wavelengths, the instrument senses heat radiating from substances in stardust itself. Molecules called polycyclic aromatic hydrocarbons glow in the infrared when warmed by M31's stars.

M31 is located 2.5 million light-years away in Andromeda. It spans about 260,000 light-years, which makes it more than 2.5 times our galaxy's diameter. — **FRANCIS REDDY**

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The Planetary Society dedicated its 72-inch SETI Optical Telescope in Harvard, Massachusetts, April 11. The scope will search for alien civilizations.

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No place on Earth experiences higher UV levels than **Cuzco, Peru.** This city is the former capital of the Sun-worshipping Incas.

A May 15 NASA report says last year's **Demonstration of Autonomous Rendezvous Technology** (DART) actually crashed into its docking target.

China's first lunar orbiter — **Chang e'l** — could launch in April 2007 and will capture 3-D images of the lunar surface.

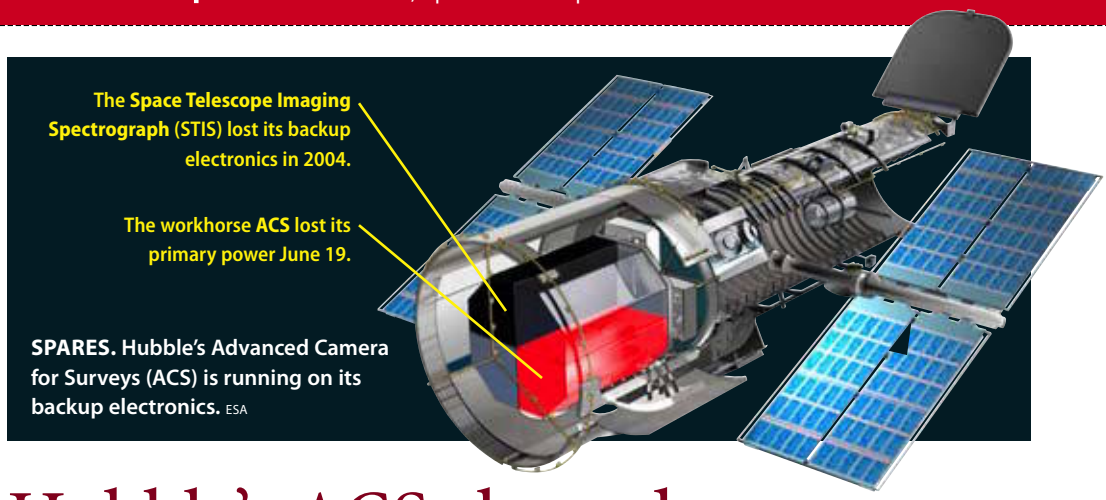
The **Mars rovers** began using upgraded flight software in August. The update lets Spirit and Opportunity process images faster and gives them new autonomous capabilities.

NASA's **Aeronomy of Ice in the Mesosphere** (AIM), slated for a September 29 launch, will study noctilucent clouds on the edge of Earth's atmosphere. Scientists hope to learn why the clouds are getting bigger, brighter, and more common.

NASA's quintuple-probe **THEMIS** mission to study Earth's aurora is set to launch this month. The acronym comes from Time History and Macroscale Interactions during Substorms.

Real Time Satellite Tracking (www.n2yo.com) lets you track the Hubble Space Telescope, International Space Station, and other satellites with your web browser.

NASA has reinstated **Dawn,** a mission to explore the asteroids Ceres and Vesta. NASA had cancelled the mission because of technical troubles and cost overruns. The agency now plans to launch Dawn next summer. **— COMPILED BY MATTHEW QUANDT**


The Space Telescope Imaging Spectrograph (STIS) lost its backup electronics in 2004.
The workhorse ACS lost its primary power June 19.

SPARES. Hubble's Advanced Camera for Surveys (ACS) is running on its backup electronics. ESA

Hubble's ACS shuts down

At 1:15 P.M. EDT on June 19, the Hubble Space Telescope's most productive instrument, the Advanced Camera for Surveys (ACS), sensed a flaw in its power supply and automatically went into safe mode, a sort of electronic hibernation.

Engineers brought ACS online June 20 using a backup power supply and associated electronics. The backup system had been well tested on the ground but had never been used in flight.

Science observations resumed late July 2. The need to recalibrate the instrument following the switch allowed scientists to do something they've always wanted to do — operate ACS' Wide Field Camera a little cooler, which will reduce electronic noise in its images. "It will actually produce more accurate quantitative data than it did before," says Dave Leckrone, Hubble senior project scientist at NASA's Goddard Space Flight Center in Maryland.

Shuttle astronauts installed the $86 million, 16.5-megapixel ACS on Hubble in March 2002. ACS was designed to operate for 5 years.

Problems with both primary and backup electronics knocked another instrument, Hubble's Space Telescope Imaging Spectrograph, out of commission in 2004. Astronomers hope a shuttle mission will service the ailing observatory in late 2007. **— F. R.**

Australian mounds formed by ancient life

AUSTRALIAN CENTRE FOR ASTROBIOLOGY/ MACQUARIE UNIVERSITY

MICROBE MOUNDS. Conical rock formations called stromatolites may be the remains of an ancient reef in Western Australia.

Scientists studying the mysterious mounds along a 6-mile-long (10 kilometers) formation in Western Australia's Pilbara region say microbes formed the structures 3.4 billion years ago. The research, led by Australian Centre for Astrobiology doctoral student Abigail Allwood and published in the June 8 issue of *Nature*, challenges the idea that chemical processes formed the rocks.

Geologists call these layered features stromatolites. Today's rare examples arise as mats of microbial colonies trap and cement particles. But ancient rock rarely preserves microbes, so proving organisms formed these structures is difficult.

Allwood found seven different stromatolite types. Each, she says, was part of an ancient reef and occupied its own niche in that environment.

"If you start at the [formation's] deep-water end and trace it along the reef system, the numbers of stromatolite shapes increase and become more complex and varied, just as occurs in biological reef systems throughout the geologic record," Allwood says. Physical and chemical processes alone can't mimic this classical environmental response. **— LAURA LAYTON**

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ASTRONOMY: ROEN KELLY

ONE OR MANY? **Repeated Big Bangs lead to a tiny cosmological constant.**

Is the Big Bang an encore?

Most cosmologists will tell you the universe began with the Big Bang 13.7 billion years ago. But a new theory, published May 5 in the journal *Science,* contends the universe is far older than this, and that the Big Bang astronomers now are trying to understand is merely the latest in a series of universe-forming cosmic cataclysms.

The cosmological constant, a mathematical representation of the energy of empty space first postulated by Albert Einstein, appears to power the universe's accelerating expansion. But the constant seems too small for a universe born in a single Big Bang. It misses the mark by at least 10 orders of magnitude (that's a 1 followed by 100 zeroes).

So physicist Neil Turok of England's University of Cambridge and Princeton University's Paul Steinhardt suggest today's cosmological constant better fits a multi-bang scenario. "There doesn't have to be a beginning of time," says Turok. "According to our theory, the universe may be infinitely old and infinitely large."

The scientists argue the universe is at least a trillion years old and underwent repeated Big Bangs. When is our universe due for another one? "All we can say," replies Turok, "is it won't be within the next 10 billion years." **— F. R.**

Hole moon

Titan's mountains may be riddled with caves. Radar scans by NASA's Cassini spacecraft suggest porous water ice forms the peaks.

NASA/ESA/RICHARD ELLIS (CALTECH)/JEAN-PAUL KNEIB (OBSERVATOIRE MIDI-PYRENEES)

SKY EYE. **Lensing galaxy clusters like Abell 2218 act like telescopes. They help astronomers image faint, distant galaxies created more than 12 billion years ago.**

Cosmic lens reveals early galaxies

Massive galaxy clusters bend and magnify light from distant galaxies, and these natural lenses help astronomers see farther. Holland Ford of Johns Hopkins University in Baltimore led a team that discovered a galaxy cluster so far away, it may have been created during the universe's first billion years.

Gravitational lensing occurs when light from a distant source bends as it travels through a gravitational field. In this case, a massive galaxy cluster provides the light-warping gravity. The phenomenon aids astronomers by boosting the images of faint background galaxies.

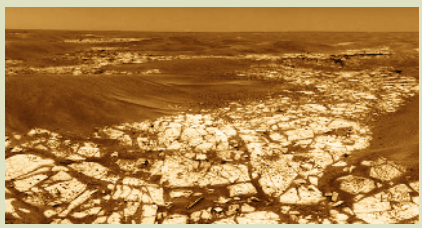
Ford's team acquired Hubble Space Telescope Advanced Camera for Surveys images of 14 strongly lensing clusters. The researchers then compared these views to images of the same clusters taken by other large scopes.

Spectroscopic study of the three brightest candidate galaxies is now under way. If this work verifies the galaxies' suspected youth, astronomers will get their clearest optical view of the early universe thanks to gravitational lenses. Ford presented the results June 5 at the American Astronomical Society meeting in Calgary, Alberta. — **L. L.**

Opportunity rover frees itself again

On May 28, NASA's Mars Rover Opportunity sank wheels-deep into a bank of loose material as it drove toward Victoria Crater. The rover's front hazard-avoidance camera recorded its stranding on a sandy ripple scientists named "Jammerbugt." The Danish word translates to "Bay of Lamentation."

Controllers backed Opportunity out of the sand trap by moving between 2 and 11 inches (5 to 28 centimeters) daily, until the rover reached the safety of a nearby rocky outcrop June 5. Following scientists' study of the material that bogged down the rover, Opportunity continued its southward trek to its next target, 2,600-foot-wide (800 meters) Victoria Crater. — **L. L.**



NASA/JPL/CORNELL

VICTORIA ROAD. **Opportunity's navigation camera looks southeast toward Victoria Crater May 12.**

A fistful of astronomy

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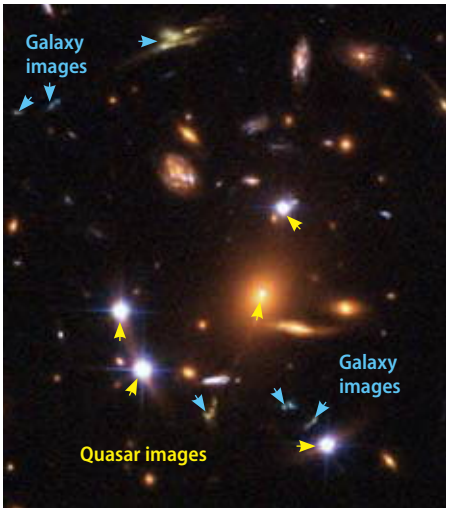


ESA, NASA, K. SHARON (TEL AVIV UNIVERSITY) AND E. OFEK (CALTECH)

QUASAR TIMES 5. **The Hubble Space Telescope imaged SDSS J1004+4112 in January and December 2005.**

Hubble images quintuple quasar

Astronomers using the Hubble Space Telescope have captured the most-detailed view yet of a distant quasar "lensed" into five separate images. Astronomers searching Sloan Digital Sky Survey data discovered the object, formally named SDSS J1004+4112.

"The special thing about SDSS J1004 is that it's the first example of a quasar that is multiply-imaged by a galaxy cluster," says team member Graham Smith of the University of Birmingham in England. The quintuple quasar's images span an unprecedented 15".

The quasar is the brilliant, black-hole-powered core of a distant galaxy some 10 billion light-years away (it lies at a redshift of 1.74). Light traveling to Earth from this cosmic beacon runs into a cluster of galaxies about 7 billion light-years away (redshift 0.68) and splits into multiple beams.

At first, astronomers counted only four quasars in SDSS J1004. But in follow-up work last year, a team led by the University of Tokyo's Naohisa Inada identified a fifth image in the bright central galaxy. Astronomers hope more such objects await discovery in SDSS data. — **F. R.**

Astro, Nextsat to test robotic docking

NASA

SPAS VIEW. **In 1983, the German Shuttle Palette Satellite (SPAS) snapped this portrait of space shuttle Challenger, which both lofted SPAS and returned it to Earth.**

For the first 20 years of space rendezvous missions, the chaser ship approached its target from a distance, flew around it or docked with it as desired, and then departed. This maneuvering was quite complicated, and it took a long while for pilots to perfect.

But beginning in 1983, when the space shuttle Challenger released the German-built Shuttle Palette Satellite (SPAS), a new and more complex choreography appeared. This was the first time a spacecraft deployed from an actively-navigating vehicle was designed to stay nearby. SPAS held its station, waiting for retrieval a few hours later by the shuttle's robot arm, while taking first-ever, breathtaking images of the shuttle in orbit. (A handful of lucky amateur astronomers — myself among them — visually saw SPAS pacing the shuttle.)

Since then, space stations and shuttles have released various objects to perform functions that needed close-up observation. Some were brought back aboard, their recorded data of high interest to astronomers, materials scientists, test engineers, and other specialists.

This month's flight of Orbital Express is another milestone. A pair of space vehicles will reach orbit, separate, and then perform a complex series of automated mutual maneuvers. The mission's purpose is to elaborate the procedures needed for future small automated spacecraft that may perform inspection, repair, and resupply of high-value space vehicles.

While the two satellites, Astro and Nextsat, perform their tasks, they will also provide targets for amateur astronomers who like observing challenges. The objects often will be quite close together and, therefore, difficult to resolve. The two craft will be in 310-mile-high (500 kilometers) orbits inclined 46° to Earth's equator. As the orbits shift through space, the satellites will pass over any given site in either daylight or deep night, not the dawn and dusk of typical satellite watching. Still, the 3-month test program — which may be extended to a year or more — offers plentiful observation opportunities for anyone at latitudes between 50° north and south.

The mission's most challenging aspect is not visible from Earth. Automated docking isn't particularly useful unless the docked robotic spacecraft can perform needed tasks. Orbital Express includes a manipulator system that will practice installing external hardware once the two spacecraft dock. A propellant-transfer experiment will attempt to move volatile liquid fuel from one vehicle to the other. If this goes wrong, some earthbound observers should see a spectacular, if brief, apparition.

Other national space programs already are developing similar spacecraft, and both Britain and Japan have made simple test flights. A Russian-led European team is building TECSAS for the same purpose, and several commercial groups in the United States and Europe have made similar proposals. Commercial communications satellites are the first proposed category of serviceable customers. To tackle these satellites, Orbital Express' descendants will need to fly very high, but the future of automated orbital repair is bright. — **JAMES OBERG**

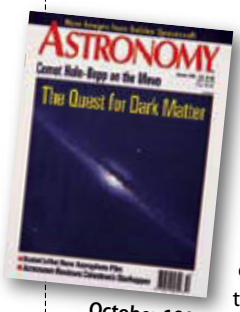
October 1981

25 years ago in *Astronomy*

In October 1981, *Astronomy* featured Voyager 2's first pictures of Saturn and previewed the spacecraft's flyby of the ringed planet. The twin Voyager spacecraft were designed for flybys of Jupiter and Saturn, but their story continues today. The two spacecraft parted ways after their Saturn encounters. Voyager 1 headed out of the solar system, while Voyager 2 explored Uranus (1986) and Neptune (1989).

Now, 29 years after they left Earth, the probes are the most distant human-made objects, and they continue to transmit data from the solar system's outer reaches. Scientists expect the Voyagers will reach interstellar space in the next decade. Their power supply should last until 2020.

10 years ago in *Astronomy*



October 1996

The theme of the October 1996 *Astronomy* was the quest for dark matter. Sound familiar? In the cover story, science writer Marcia Bartusiak explained how even the most knowledgeable scientists can't answer one of the most fundamental questions: What is the universe made of?

In the same issue, then Senior Editor David J. Eicher also alerted readers to Comet Hale-Bopp's spectacular naked-eye appearance in the evening sky. Hale-Bopp, the last great comet to dominate the night sky, had a flare for the dramatic. In October and November, the comet gave observers a sneak peak of its spectacular spring 1997 appearance.

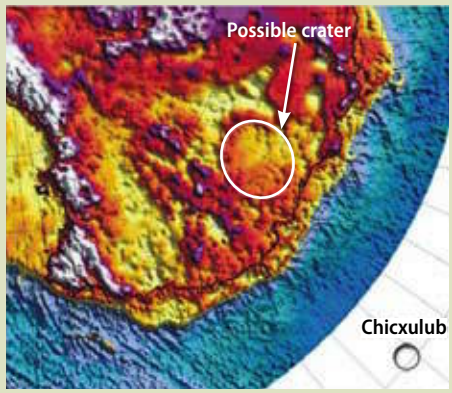
Antarctic ice may hide giant crater

Gravity fluctuations detected by spacecraft, together with airborne radar images, hint that an impact structure as large as the state of Ohio lies beneath Antarctica's massive, mile-thick ice sheet.

Ralph von Frese and Laramie Potts at Ohio State University in Columbus led the team that made the find. They presented the results at the May meeting of the American Geophysical Society in Baltimore.

NASA's Gravity Recovery And Climate Experiment (GRACE) indicated a 200-mile-wide (320 kilometers) mass concentration, or "mascon" in geological parlance, under the ice sheet in the Wilkes Land region of East Antarctica, south of Australia. Mascons form where asteroids or comets slam into a planet's surface and denser mantle material bounces up into the overlying crust. "If I saw this same mascon signal on the Moon, I'd expect to see a crater around it," von Frese says.

When the team compared the gravity data to radar images that show topography, the mascon appeared nestled in a 300-mile-wide circular ridge. Geologists will need to drill the crater to prove an impact caused it. **— F. R.**



ICEBOUND. Airborne radar shows where a possible crater lies beneath a mile of Antarctic ice. The circled area is 3 times bigger than Mexico's famous Chicxulub Crater.

BRIEFCASE

Growth limit

The moon-to-planet-mass ratios are nearly constant — 1:10,000 — for Jupiter, Saturn, Uranus, and Neptune. Simulations by scientists at the Southwest Research Institute in Boulder, Colorado, show this curiosity because a lack of hydrogen gas limited the moons' sizes. The results appear in *Nature*'s June 15 issue. **— L. L.**

Eye for clouds

University of Washington researchers are studying how suspended particles affect Earth's climate with NASA's CALIPSO (Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation), launched April 28. In June, CALIPSO's laser measured cloud altitudes to within 100 feet (30 meters). **— L. L.**

Earth wobbles

Scientists using Global Positioning Satellite data have traced looping changes as small as a cell phone in the position of Earth's axis. Sebastien Lambert of Belgium's Royal Observatory thinks weather systems and ocean currents create the short-term wobbles. The research appears in the July 1 issue of *Geophysical Research Letters*. **— F. R.**

NASA antenna network needs upgrades, repairs

NASA

FRAGILE AT 40. NASA's dish network could lose data.

The 40-year-old global antenna network that communicates with distant spacecraft like Cassini and Voyager is aging and fragile, says a report by the General Accounting Office. During a period of 5 months last year, NASA's Deep Space Network (DSN) suffered antenna outages that resulted in the loss of 241 minutes of data from Stardust, Deep Impact, and three Mars orbiters.

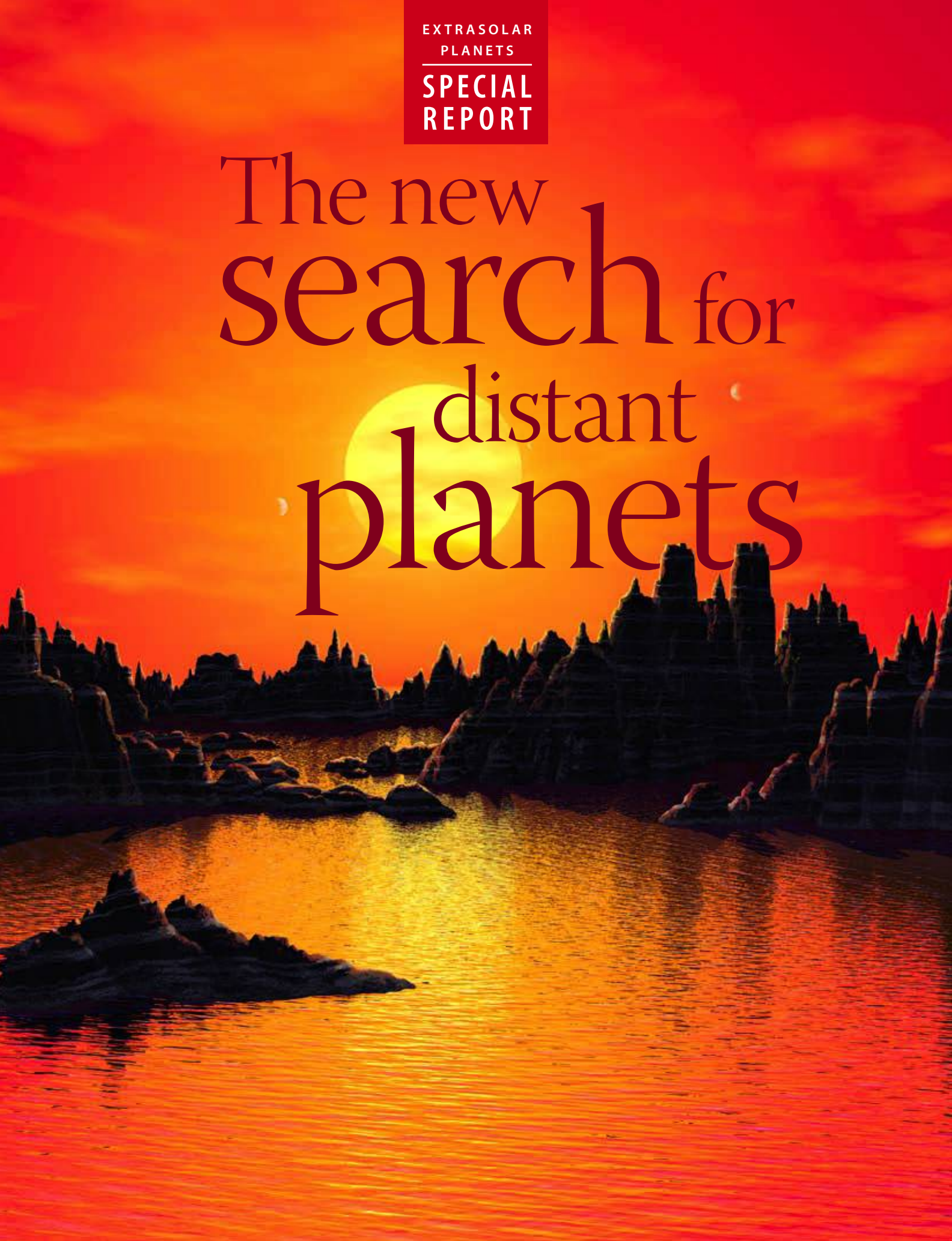
DSN officials say parts of the system are shut down for repairs an average of 16 hours a week. They worry about metal fatigue on the network's 16 dish-shape antennae located in Goldstone, California; Madrid; and Canberra, Australia.

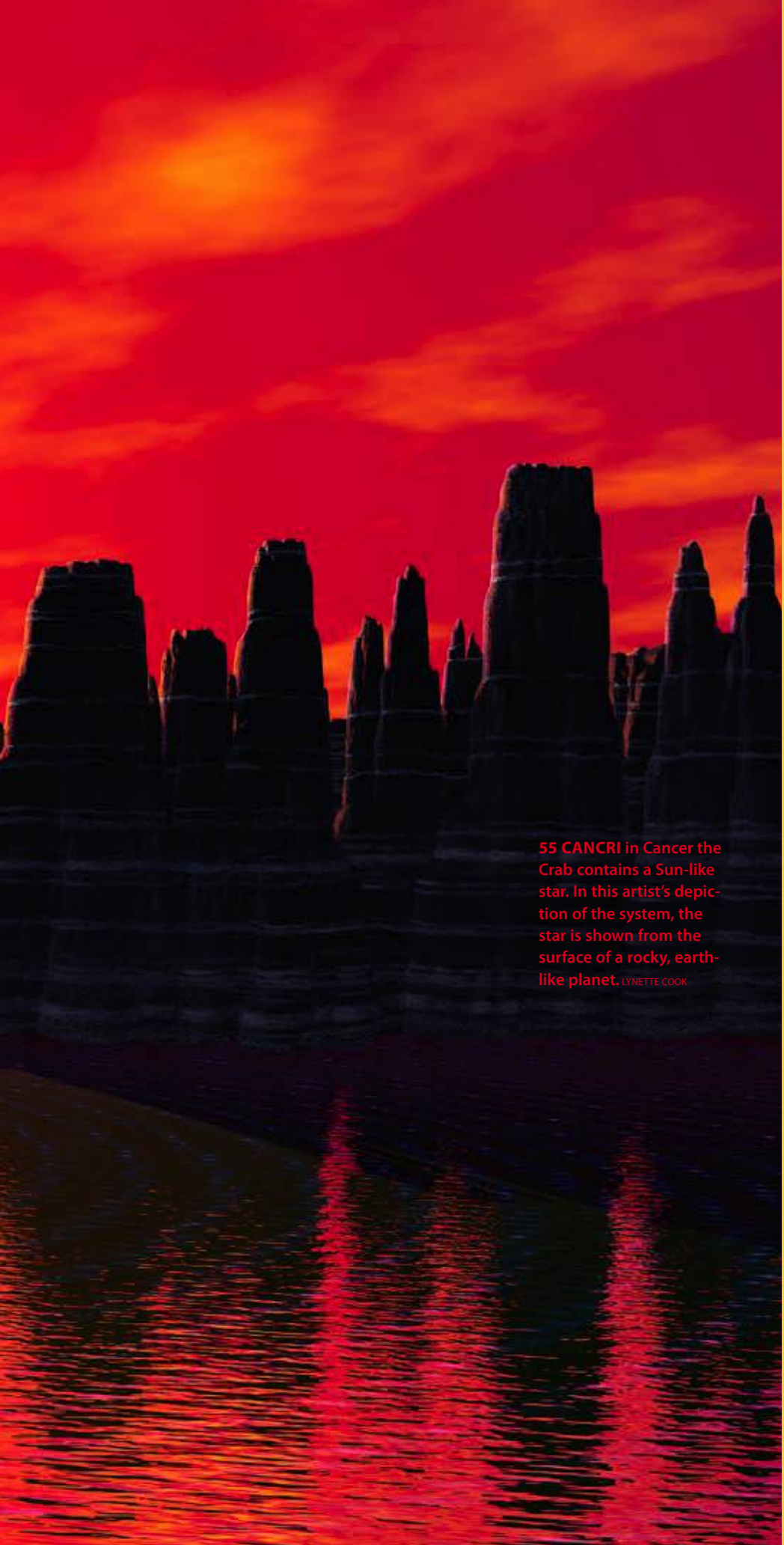
NASA has deferred about $30 million in DSN maintenance projects annually since 2002. "The potential exists for the loss of scientific data that would be difficult, if not impossible, to replace," says the report. **— F. R.**

EXTRASOLAR PLANETS

SPECIAL REPORT

The new search for distant planets





55 CANCRI in Cancer the Crab contains a Sun-like star. In this artist's depiction of the system, the star is shown from the surface of a rocky, earth-like planet. LYNETTE COOK

At 200 exoplanets and counting, astronomers are much closer to discovering worlds that might resemble our own.

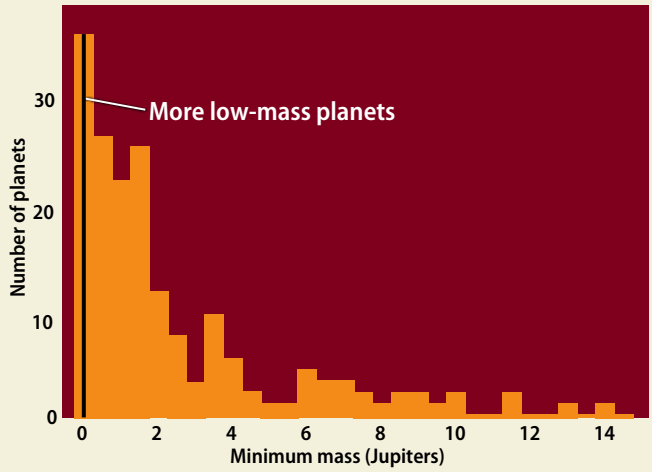
/// BY GEOFFREY W. MARCY

For centuries, friends have gathered for lunch and conversation at outdoor cafés in northern Greece. Under the hot Sun, surrounded by appetizers and rounds of ouzo, conversations have often meandered toward the heavens, sparking heated debates about the existence of other fertile worlds. If those worlds also harbor citizens, might they also gaze toward the stars? Such café philosophers flourished in 400 B.C., when Democritus taught his students about the possibility of other habitable worlds of great diversity, and of the likelihood of life on them. Modern astrophysics is finally poised to answer the Greek philosophers' questions about other worlds and the possibility of life on those worlds. In the past 10 years, some 200 planets have been discovered around nearby Sun-like stars.

New worlds found

Michel Mayor and Didier Queloz of the Observatory of Geneva in Switzerland discovered the first exoplanet orbiting a main sequence star in 1995 — a Jupiter-size object orbiting Sun-like star 51 Pegasi. Their findings appeared in the November 23, 1995, issue of *Nature*. Within the next 3 months, Paul Butler and I discovered the second and third exoplanets orbiting Sun-like stars 47 Ursae Majoris and 70 Virginis, respectively, while at San Francisco State University. We reported our discovery in the June 1996 issue of the *Astrophysical Journal*. These discoveries gave

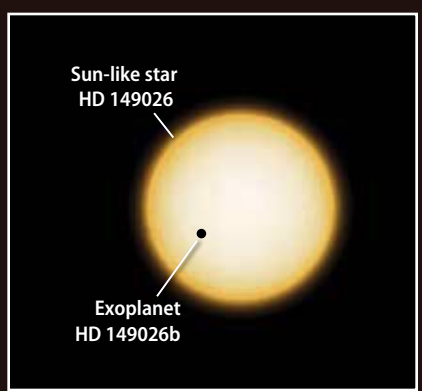
Exoplanets' mass distribution



LOW-MASS planets dominate the ever-increasing group of some 200 extrasolar planets discovered to date.

ASTRONOMY: ROEN KELLY, AFTER GEOFFREY W. MARCY

THE FIRST exoplanets orbiting Sun-like stars gave birth to the new field of extrasolar planetary science.



ASTRONOMY: ROEN KELLY, AFTER GEOFFREY W. MARCY

EXOPLANET HD 149026b orbits its host star in just under 3 days from a distance of about 0.042 AU. Astronomers detected the planet orbiting Sun-like star HD 149026 in 2005. The planet's mass and radius are similar to Saturn's: 1.145 Saturn masses and 0.88 Saturn's radius.

birth to the new field of extrasolar planetary science. The parade of discoveries has continued nonstop since then.

Astronomers have discovered most of the known exoplanets by detecting the reflex motion of their host stars as they were yanked gravitationally by their orbiting planets. As the star wobbles toward us and away, its emitted light waves are alternately compressed and stretched. Earthbound telescopes equipped with spectrometers that spread the starlight into its composite colors can detect this Doppler effect. However, only planets the size of Jupiter, Saturn, or Neptune have been detected using the Doppler method because only such giant planets have enough gravitational pull to yank the stars around by a detectable amount.

The giant planets found around other stars have startling properties. About 90 percent of them travel in elongated, eccentric orbits more akin to the comets in our solar system. Therein lies a possible origin of those eccentricities. Other planets or the exoplanet-forming protoplanetary disk can exert a gravitational force that pulls an exoplanet out of its original circular orbit. Similarly, Jupiter's strong gravitational field sling-shot comets in the Oort Cloud into distant, elongated orbits.

Another oddity is that many extrasolar giant planets — including the first ones found — orbit closer to their stars than the Earth is to the Sun (1 AU). These tight orbits defy conventional planet-formation theories in which giant planets form in the cooler, slower-moving outer reaches of a planetary system, where gas can settle gently onto rocky cores. Exactly how giant planets migrate inward and then park themselves close to their host stars remains a puzzle.

Geoffrey W. Marcy *is a professor of astronomy at the University of California, Berkeley, and a leading exoplanet-hunter. He heads the team credited with discovering the most exoplanets.*

The smallest exoplanet

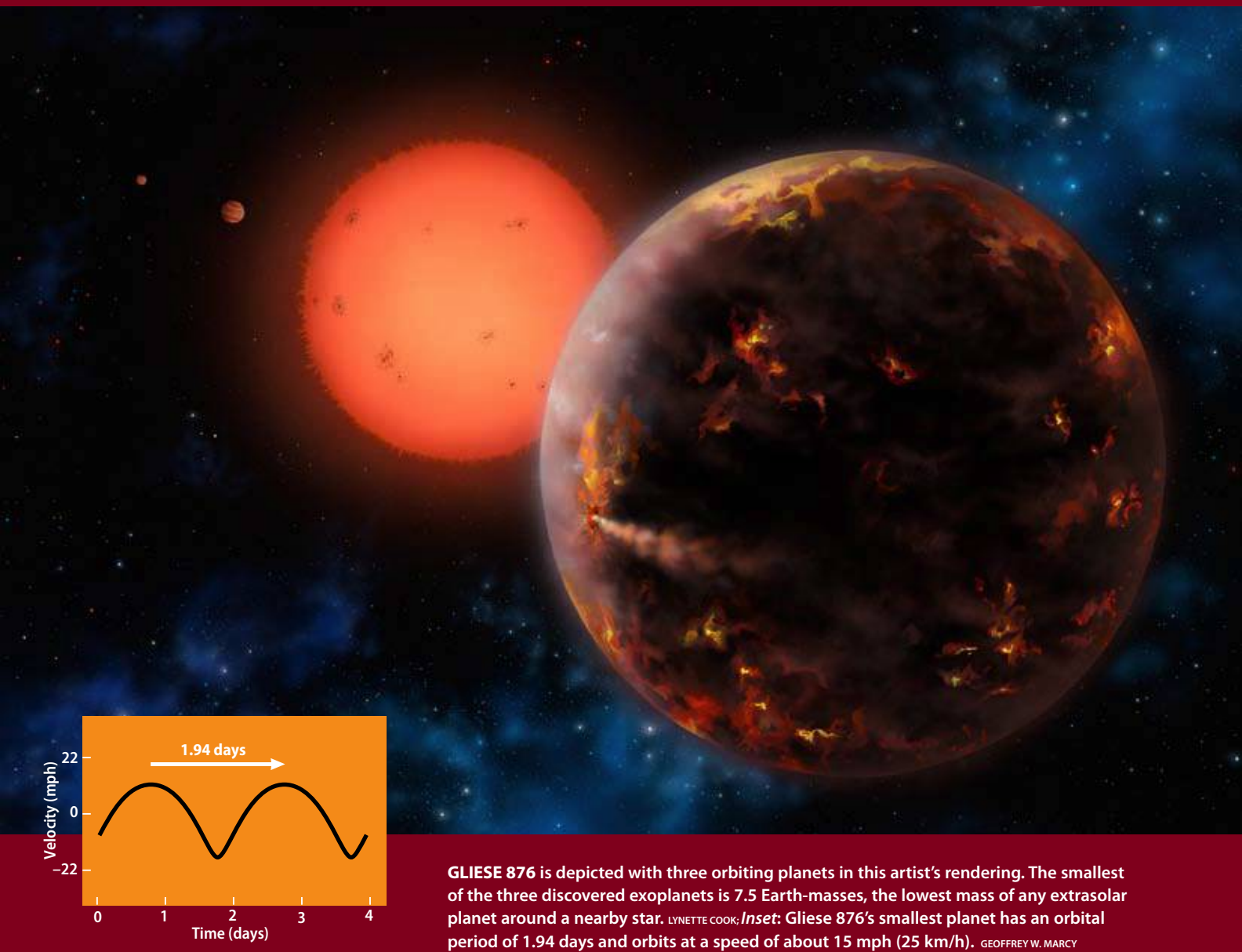
Improvements in Doppler technology allow us to measure stars' velocities to within 2 miles per hour (3 km/h), or human walking speed, which has permitted discovery of smaller and smaller planets. Our team detected the smallest planet yet found around a nearby star, Gliese 876: a 10th-magnitude red dwarf that is only 15 light-years away. This fascinating star has two Jupiter-size planets with orbital periods of 30 and 61 days in a resonance that causes them to gravitationally shepherd each other, keeping them locked in that 2:1 period ratio.

As we monitored those two Jupiter-size exoplanets with the world's largest telescope, the Keck I in Hawaii, we were surprised the star exhibited an additional wobble not explainable by the two exoplanets. We found that a third planet of 7.5 Earth-masses and a remarkably short orbital period of only 1.9 days causes the additional wobble. Normally, the Doppler method reveals only a planet's minimum possible mass, which is limited by the unknown tilt of the orbital plane. But, in this fortuitous find, the two Jupiter-size exoplanets exert gravitational forces on each other that we detect, thereby establishing their orbital plane that, in turn, sets all the planet masses precisely.

A Doppler team led by Christophe Lovis in Geneva recently discovered a system of three Neptune-size planets with minimum masses of 10, 12, and 18 Earths orbiting HD 69830, a 5.95-magnitude, spectral-type K0 star about 15-percent less massive than the Sun. The star is just visible to the naked eye.

Astronomers using the Spitzer Space Telescope discovered an asteroid belt outside the system of the three Neptune-size planets. They examined infrared-light emission from the dust to make the discovery. Thus, this system has properties similar to our solar system, which indicates planetary systems like ours may be common.

Three planets orbiting Gliese 876



GLIESE 876 is depicted with three orbiting planets in this artist's rendering. The smallest of the three discovered exoplanets is 7.5 Earth-masses, the lowest mass of any extrasolar planet around a nearby star. LYNETTE COOK; *Inset*: Gliese 876's smallest planet has an orbital period of 1.94 days and orbits at a speed of about 15 mph (25 km/h). GEOFFREY W. MARCY

Two more detection methods

Adding to the planetary parade are two marvelous new detection techniques: gravitational microlensing and transit. Gravitational microlensing occurs when light from a distant background star bends around a planet and briefly amplifies ("lenses") the star's light. Two planets of 5 to 15 Earth-masses were discovered recently by this method with orbital distances between those of Mars and Jupiter.

About 8 planets have been discovered using the transit method, during which a planet crosses in front of and dims its host star. This technique provides a direct measure of an orbiting planet's diameter. The bigger the planet, the more starlight it blocks. Combined with the Doppler technique, which gives the masses of the planets, we can determine the planets' densities by dividing the planet's mass by its volume. Giant planets have densities near that of water, 1 gram per cubic centimeter (about the volume of a sugar cube), which is similar to Jupiter and Saturn's. Thus, most exoplanets found so far are gaseous objects.

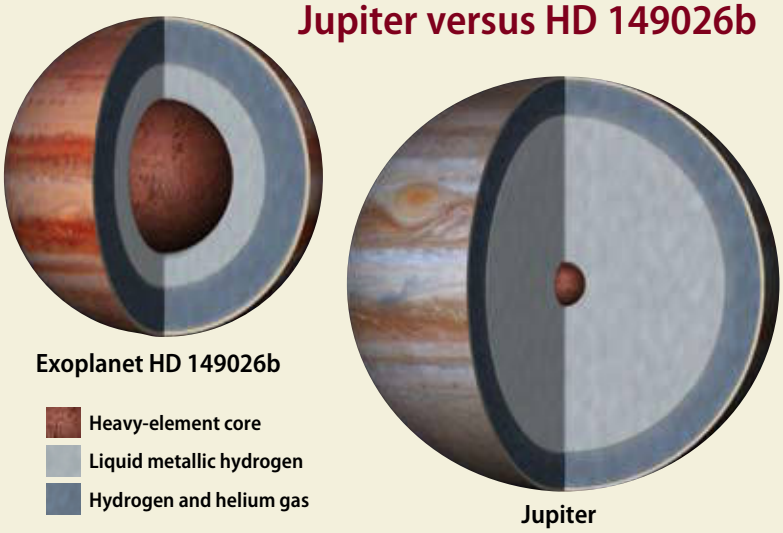
Searching for super-Earths

The exoplanets of lowest mass point toward a new class, called super-Earths — exoplanets with masses greater than 1 but less than 14 Earth-masses. Interestingly, our solar system is devoid of planets in this range. Super-Earths represent the next great terra incognita to be explored — worlds larger than Earth but smaller than Uranus.

If super-Earths actually form, would they be rocky like the terrestrial planets, gaseous like Jupiter and Saturn, or icy and gaseous like Neptune and Uranus with a large rocky core? No one knows.

But observations give early clues about the existence and composition of super-Earths. Nature appears to make many more Saturn-mass planets than Jupiter-mass ones, and Neptune-mass planets seem even more abundant. Extrapolation suggests there might be yet more of the

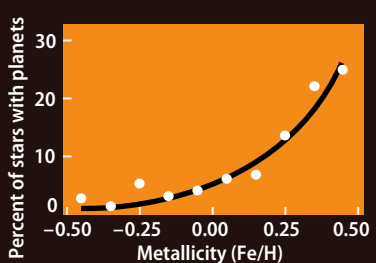
Jupiter versus HD 149026b



SUPER-EARTH HD 149026b has a composition similar to Jupiter's. The exoplanet's core is composed of heavy elements surrounded by a layer of liquid metallic hydrogen. Its outer layer comprises hydrogen and helium gases. *ASTRONOMY*: ROEN KELLY, AFTER GEOFFREY W. MARCY

HD 149026b MUST have an even greater concentration of rocky and iron material than Saturn.

Planet – metallicity correlation



ROCK AND IRON play significant roles in planet formation. Astronomers who studied 1,000 stars on their planet-search list found a correlation between the percentage of stars with planets and the abundance of heavy elements, like iron, within the stars.

ASTRONOMY: ROEN KELLY, AFTER GEOFFREY W. MARCY

lower-mass super-Earths than all the giant planets combined.

Some known gaseous exoplanets may have rocky super-Earth cores. The best example of a likely rocky core is inside the transiting exoplanet HD 149026b, discovered by Debra Fischer of San Drancisco State University. This planet has a 15-percent larger mass than Saturn but a 10-percent smaller radius. How could a planet be more massive, yet smaller in size? The apparent compaction of this Saturn-like planet can be explained only by its having a high concentration of heavy atomic elements that increases its gravity and, hence, final density.

Saturn has a rocky core 20 times Earth's mass. The Saturn-like exoplanet HD 149026b must have an even greater concentration of rocky and iron material than Saturn, and calculations by Peter Bodenheimer and collaborators suggest the rocky core is 50–70 Earth-masses. That whopper of a super-Earth is buried under an envelope of 30 Earth-masses of hydrogen and helium gas and strongly suggests nature has no trouble making such enormous cores of silicates and iron. Indeed, exoplanets predominantly orbit stars rich in heavy elements, indicating rock and iron play strong roles in planet formation.

How would a super-Earth form?

Theorists have their own predictions about super-Earth formation. They predict rocky planets under 15 Earth-masses form when dust particles in the protoplanetary disk clump together. As dust sticks together and grows, like dust bunnies behind your bed, the largest blobs grow faster and faster as their large sizes allow them to collide frequently with ever more dust. These dust-and-ice blobs act like a thick sea of "planetesimals." The largest planetesimals begin gravitationally attracting smaller planetesimals, causing large ones to grow even faster.

Planet-formation models by Peter Goldreich, Yoram Lithwick, Re'rm Sari, Scott Kenyon, and Benjamin Bromley all agree about the next planet-formation steps. (The scientists are from Caltech, UC Berkeley, Caltech, the Smithsonian Astrophysical Observatory, and the University of Utah, respectively.) Rich planetesimals get richer and, after about 10 million years, Mars-size planets form. Dozens of such planets may orbit a typical young star.

Mars-size planets perturb each other gravitationally, causing orbits to cross and, eventually, collide violently with each other. Crushing upon impact, they stick and grow into Venus- or Earth-size planets after some 20–40 million years. Glancing impacts by two such planetesimals can result in ejected magma, which can form a large moon, as presumably created our Moon.

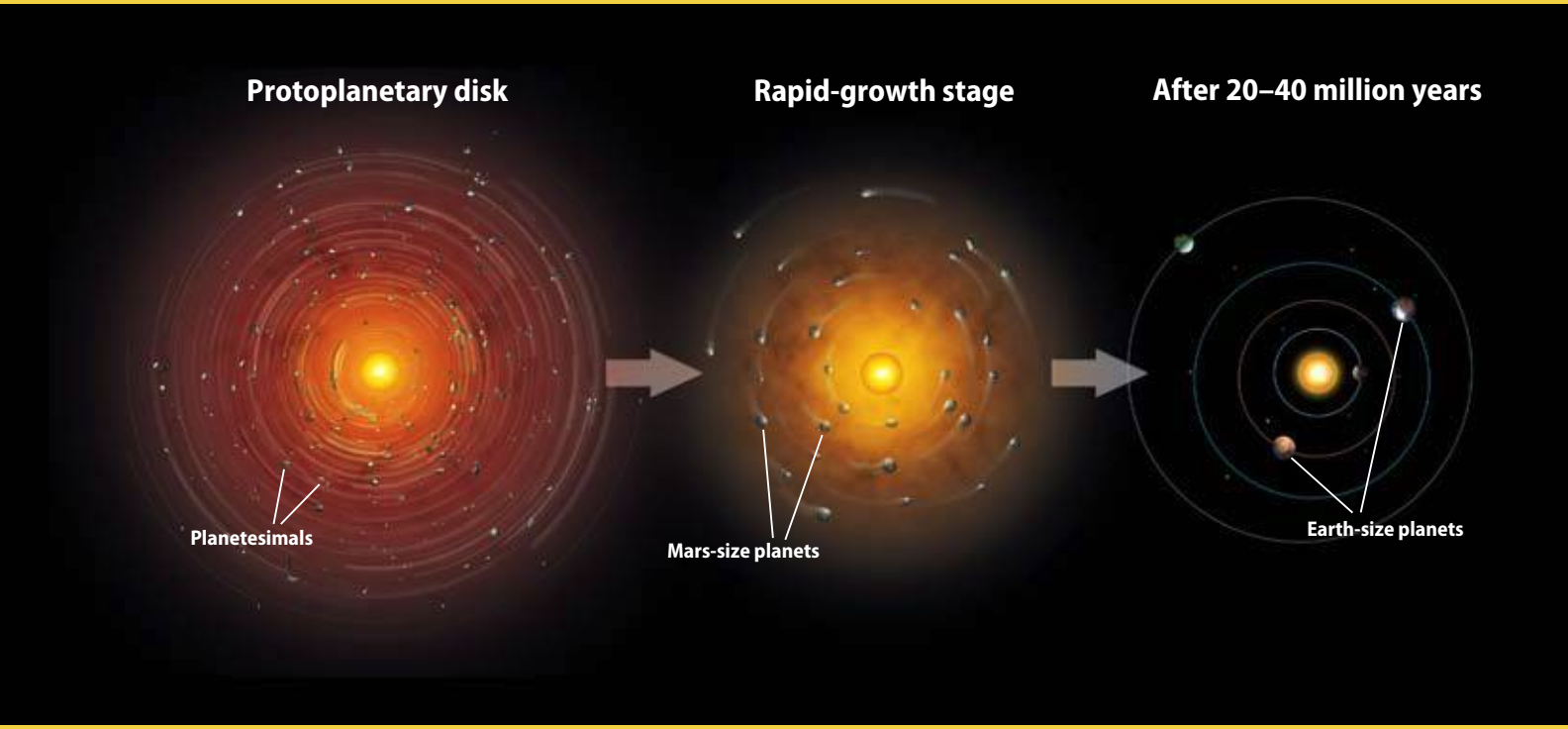
Theory predicts protoplanetary disks that are particularly rich in silicate dust or ice particles will give birth to especially large rocky planets of 5–10 Earth-masses. After all, why should Earth represent the largest rocky planet possible in the universe? Super-Earths must have massive iron-nickel cores compressed to somewhat higher densities, and they would have massive mantles heated by radioactive uranium, warming the interiors to tens of thousands of degrees Fahrenheit.

A fine line between ice and water

Many super-Earths will form within the disk's "ice line," located about 2 AU from the star, near our asteroid belt. The temperature within that distance is too high for ice crystals to exist. Super-Earths formed within the ice line will be composed mostly of silicates, iron, and nickel, as is Earth.

However, water could be delivered to such inner rocky planets by ice-rich asteroids, which astronomers think are abundant in our own solar system. A Jupiter-like planet would gravitationally perturb the

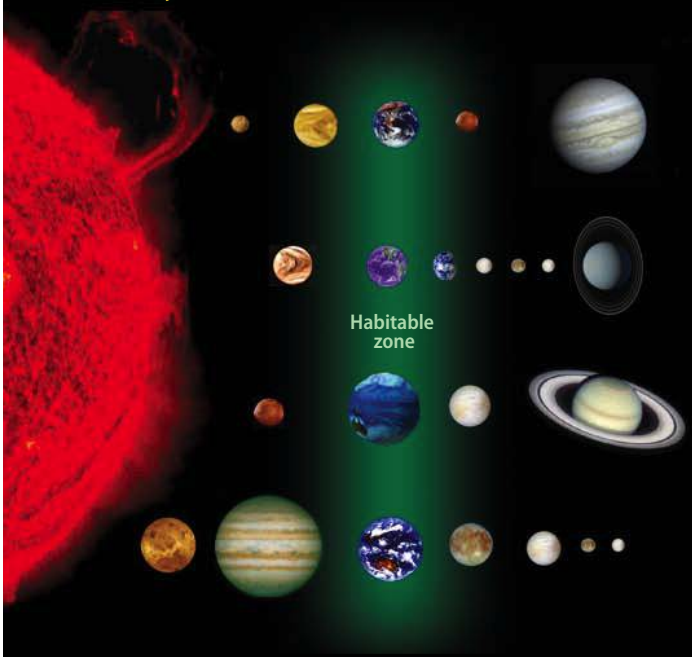
A theory of rocky-planet formation



ROCKY PLANETS exhibit orderly growth through collisions of planetesimals (mile-wide comets and asteroids). Gravitational attraction focuses the planetesimals' orbits, which results in rapid growth that produces Mars-size planets in about 10 million years. The planets eventually merge, growing to Earth's size in some 20–40 million years.

ASTRONOMY: ROEN KELLY, AFTER JEFFREY BENNET ET AL. IN *THE COSMIC PERSPECTIVE*

Diversity and the habitable zone



◀ **OUR SOLAR SYSTEM** contains 4 terrestrial planets: Mercury, Venus, Earth, and Mars. Earth, the third planet from the Sun, lies within the star's habitable zone. Gas-giant Jupiter lies outside it.

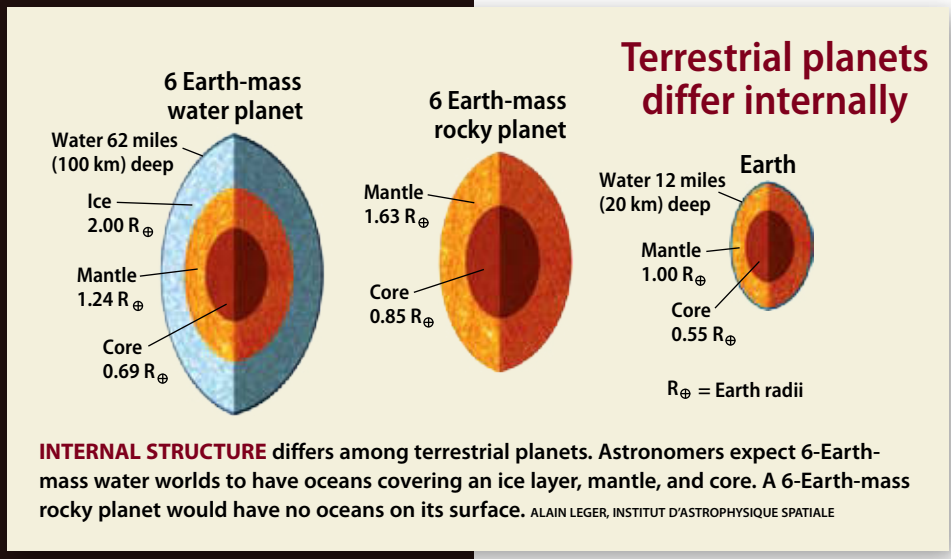
◀ **SIX TERRESTRIAL** planets lie in this theoretical planetary system. The second planet from its star is about Earth-size. The giant planet, the seventh from the star, is Neptune-size.

◀ **A "WATER WORLD"** terrestrial planet lies second-closest to its star in this theoretical planetary system. The huge planet has 4 times Earth's mass and 25 times the water. The planet closest to the star is dry, while the fourth, outermost planet is icy.

◀ **A MASSIVE INNER** terrestrial planet is the hallmark of this theoretical planetary system. The planet lies closest to its host star, followed by a "hot Jupiter," and a 3 Earth-mass planet that lies within the star's habitable zone.

ASTRONOMY: ROEN KELLY, AFTER SEAN RAYMOND, UNIVERSITY OF COLORADO

DIVERSITY ABOUNDS in planetary systems both real and theoretical. In each system, the majority of terrestrial planets lies outside the star's habitable zone, a region where the temperature is right for the presence of liquid water.



INTERNAL STRUCTURE differs among terrestrial planets. Astronomers expect 6-Earth-mass water worlds to have oceans covering an ice layer, mantle, and core. A 6-Earth-mass rocky planet would have no oceans on its surface. ALAIN LEGER, INSTITUT D'ASTROPHYSIQUE SPATIALE

NASA

NASA'S KEPLER spacecraft will search the Milky Way Galaxy for Earth-size and smaller extrasolar planets. Kepler is scheduled to launch in October 2008.

GEOFFREY W. MARCY

NASA'S SIM PlanetQuest spacecraft will search 2,000 nearby stars for exoplanets ranging from Earth-size to Neptune-size. (Image is not to scale.)

hydrated asteroids into Earth-crossing orbits. The asteroids would eventually slam into the terrestrial planets and bring water to them. In this way, rocky planets can acquire various amounts of water, depending on how perturbative the Jupiter-like planet happens to be (due to its mass or orbital eccentricity).

Thus, some rocky planets might be nearly devoid of water — mere desert worlds without lakes, rain, or oceans. Other planets could receive 10 times, or even hundreds of times, the number of hydrated asteroids that Earth did, covering those worlds completely with a thick ocean. After all, if Earth had just twice its volume of ocean water, hardly any land would poke above sea level.

However, some planets may form beyond the ice line, in the cold outer reaches of the protoplanetary disk. There, ice particles dominate, comprising 3 times more mass than silicate dust particles. Protoplanets formed there will be composed of as much water as rock. The moons around Jupiter and Saturn are just such water worlds, albeit frozen and small. Callisto, Dione, and Enceladus are such worlds, having as much water-ice as rock. If any of those moons had migrated closer to the Sun, the added heating from sunlight would have melted them into liquid water worlds. Many Earth-mass-and-above planets located within 1 AU of their host stars may be such water worlds, with thick oceans and no continents.

Planet quest in full swing

The coming decade will see the Greek philosophers' planetary quest met with various instruments designed to detect super-Earths around Sun-like stars. In 2008, the Kepler mission is scheduled for launch. It will be a 3-foot (1 meter) telescope with a 95-megapixel camera consisting of 42 charge-coupled devices (CCDs) to monitor 100,000 stars of roughly 12th magnitude in a field of view of 105 square degrees.

The stars' brightnesses will be monitored with a precision of one part in 100,000 to detect dimming caused by transiting Earth-size planets. The Kepler mission will give us a statistical measure of the occurrence of planets from Earth-size to super-Earths to Neptune-size orbiting within 2 AU of normal stars. For the first time, we may know how common other rocky worlds are.

NASA's Space Interferometry Mission (SIM) PlanetQuest is designed to detect planets of 3 Earth-masses or larger that orbit stars within 20 light-years of Earth. SIM PlanetQuest will use two telescopes separated by 295 feet (90m) as an interferometer combining visible light waves at a common focus. The enhancement or cancellation of

DETECTING HABITABLE planets within 20 light-years of Earth would represent a milestone in science.

light-wave crests and troughs from each telescope determines a star's position in the sky with an incredible accuracy of 1 millionth of an arcsecond. Thus, SIM PlanetQuest will hunt for the wobbles of stars pulled around by super-Earths orbiting between 0.1 and 2 AU from their host stars — where liquid water should be. Unfortunately, NASA's recent budget mandate, which emphasizes putting people back on the Moon, and fixing the space station, has delayed SIM PlanetQuest's launch date until at least 2015.

Meanwhile, the tried-and-true Doppler technique, responsible for locating some 185 exoplanets already, will get a boost with the completion of the "Rocky Planet Finder" Telescope at Lick Observatory. This 7.9-foot (2.4m) Hubble-size telescope will hunt for rocky planets 365 nights per year. The Rocky Planet Finder Telescope will robotically measure stars' wobbles

PLANET-HUNTER and Berkeley professor Geoffrey W. Marcy leads a team of researchers and extrasolar planet-hunters. The group has found the most exoplanets to date. LAURIE HATCH

THE ROCKY PLANET FINDER, also known as the Automated Planet Finder (APF) Telescope, is currently under construction at Lick Observatory. Extrasolar planet-hunter and University of California, Berkeley, professor Geoffrey Marcy and planet-search team member and Berkeley professor Debra Fischer stand outside the dome surveying APF's progress. LAURIE HATCH

with a precision of 2 miles per hour (3 km/h), using a specialized, high-resolution spectrometer designed by Steve Vogt of the University of California, Santa Cruz, famous for his construction of two previous planet-hunting spectrometers. Nightly measurements will detect rocky, 1–15 Earth-mass worlds orbiting within 0.5 AU of their stars by the gravitational wobbles they impart to their host stars.

The Rocky Planet Finder Telescope is scheduled for completion late next year. But funds for its operation are still needed, and the telescope has no official name. Nonetheless, the detection of rocky planets around nearby stars portends a new era in planet-hunting.

By targeting 200 nearby stars with the Rocky Planet Finder Telescope, planets with rocky surfaces and lukewarm temperatures will be detectable. Such warm planets would likely have surfaces with liquid water, serving as the solvent for biochemical reactions necessary for life to arise. Detecting habitable planets within 20 light-years of Earth would represent a milestone in science and answer a question posed by the ancient Greeks. Finding habitable planets would answer one of the most central questions of humanity: Do other habitable worlds exist? If so, what is their occurrence rate for stars slightly less massive than the Sun?

Searching for intelligent life

One great value of nearby habitable worlds is the ability to check them for signs of intelligent life. We will use Earth's major radio and optical telescopes to search for regular, pulsing signals from our newly discovered habitable worlds; only a technological civilization could produce regular signals. We plan to use the Allen Telescope Array (ATA), the new radio telescope by the University of California, Berkeley, and the SETI Institute, for this purpose. The ATA, its construction already under way, will enable high-sensitivity monitoring of our newly discovered habitable worlds to search for radio signals from intelligent civilizations. We will also search for extraterrestrial-intelligence signals in optical and near-IR wavelengths.

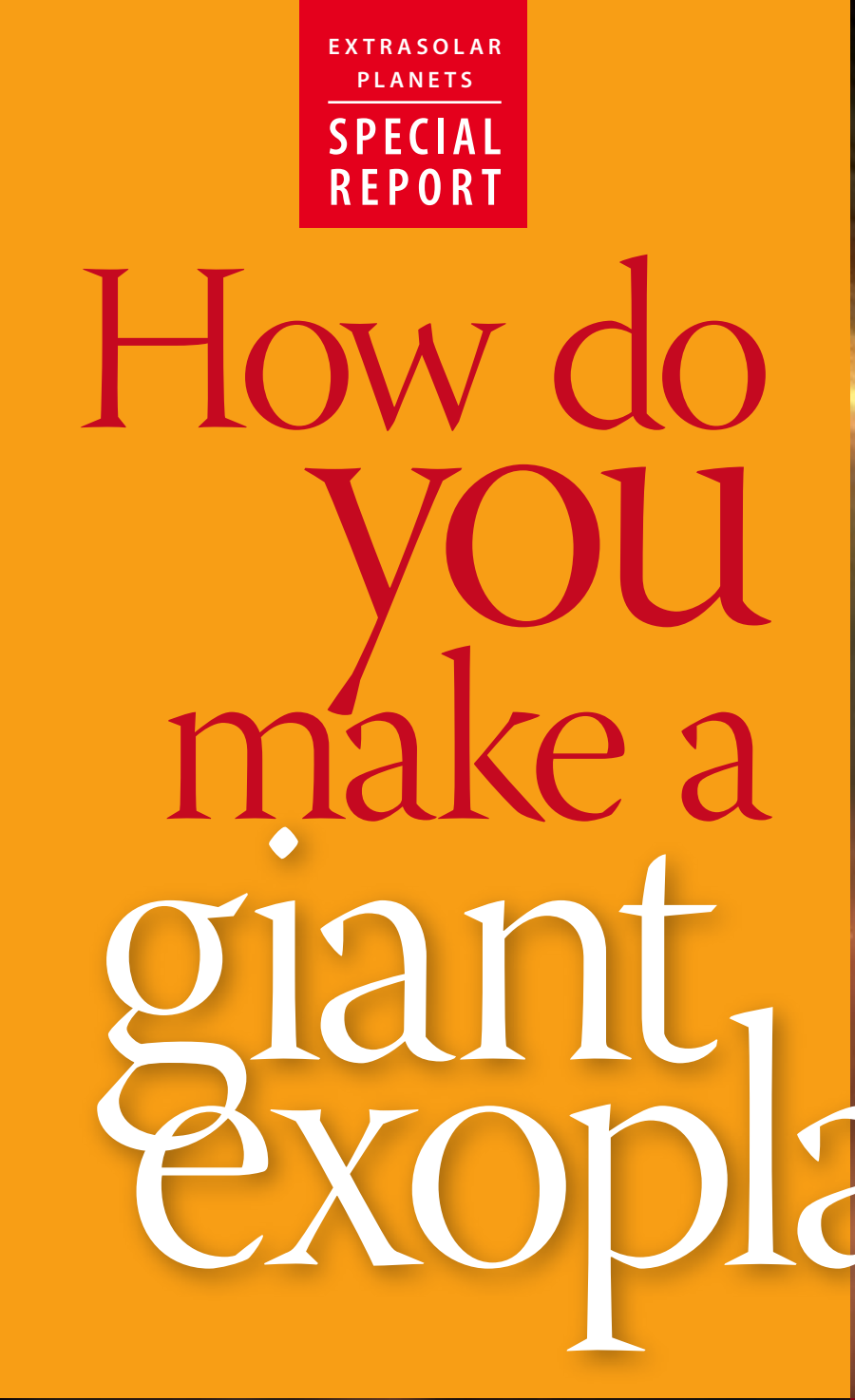
Perhaps within our lifetimes, or those of our grandchildren, we may sit at outdoor cafés along the Mediterranean neither wondering if other habitable worlds exist nor pondering if anyone lives on them. Instead, we may already know that we are not alone. If so, the lunchtime debates may focus on what constitutes "civilized" behavior in the eyes of our galactic neighbors.

ONLINE EXTRA To get the latest information on extrasolar-planet discoveries, visit www.astronomy.com/toc.

EXTRASOLAR PLANETS

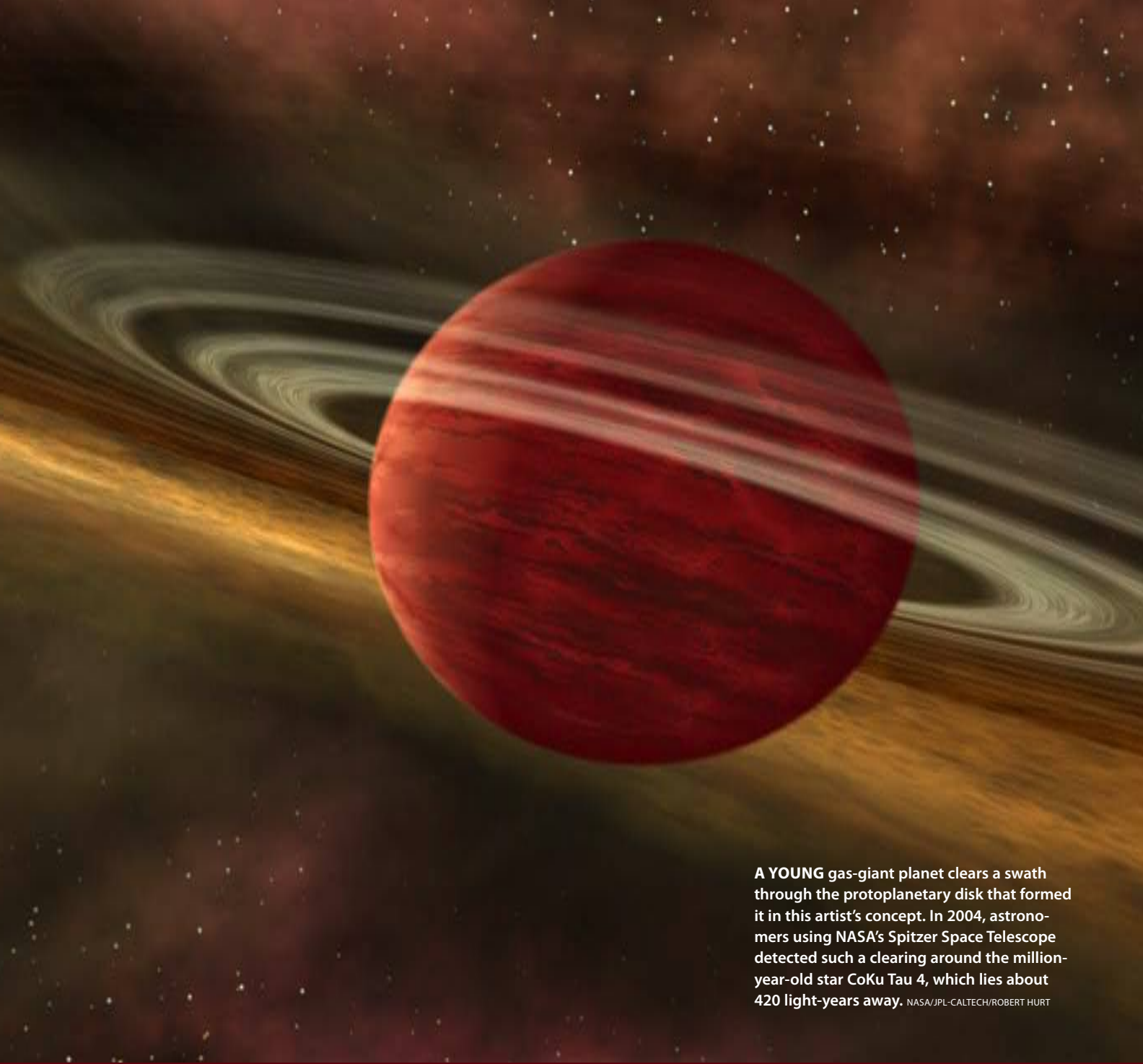
SPECIAL REPORT

How do you make a giant exoplanet?



Scientists endlessly debate theories of how giant planets form, but only observations will settle the question. /// BY ALAN P. BOSS

◀ **KNOTS OF GAS** appear in the disk of matter around a young star in this illustration. Some of these knots will give rise to gas-giant planets like Jupiter. DANA BERRY, SKYWORKS DIGITAL



A YOUNG gas-giant planet clears a swath through the protoplanetary disk that formed it in this artist's concept. In 2004, astronomers using NASA's Spitzer Space Telescope detected such a clearing around the million-year-old star CoKu Tau 4, which lies about 420 light-years away. NASA/JPL-CALTECH/ROBERT HURT

For several decades, theorists have worked to understand the solar system's origin, with mixed results. All agree that Earth, Mercury, Venus, and Mars — the so-called terrestrial planets — formed as progressively larger rocky bodies banged together. But theories now in vogue have trouble accounting for the solar system's massive gas giants, Jupiter and Saturn. That's a problem because most of the more than 200 exoplanets astronomers know about are also giants. This leaves scientists with no widely accepted mechanism for formation of the planets found beyond the solar system.

In a field just over a decade old, explaining why we see what we see is an important first step, but the goal is to make predictions future observations can test. Yet, even as theorists go back and forth over giant-planet formation, astronomers have discovered evidence for the existence of rocky extrasolar planets. These objects, with masses several times Earth's, appear to validate what astronomers think they know about how terrestrial planets form.

Building rocky planets

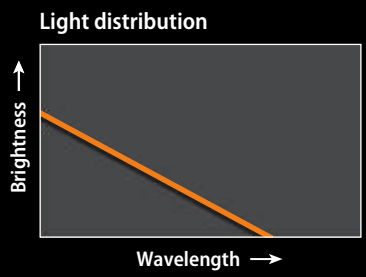
Earthlike planets grow as micrometer-size grains collide and stick together, forming pebbles. The pebbles collide to make boulders, which smash together to build kilometer-size planetesimals. Planetesimals are massive enough that their own gravity helps them grow further. That is, two bodies that would otherwise miss one another collide

Deducing Disks

THE DEBRIS DISKS that produce planets are often too small for telescopes to image directly. But looking at the central star's spectrum, which reveals its chemical make-up and temperature, tells the tale. *ASTRONOMY:* ROEN KELLY

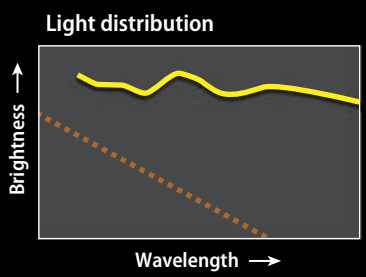
Star with no disk

The distribution of light at any given wavelength follows a specific pattern based on physical laws and the star's temperature. This star emits most of its energy at short wavelengths and less energy at longer wavelengths.



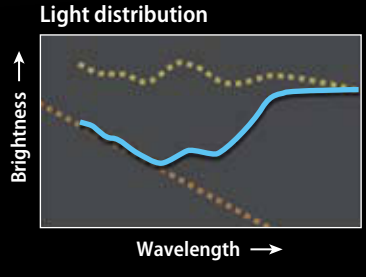
Star with a full disk

The warm disk of dust and gas surrounding the star makes its own spectral contribution. The cooler material emits most of its energy at long (infrared) wavelengths, revealing the disk's presence.



Star with a disk gap

A low-temperature bump in this star's spectrum indicates a disk with a missing center. It may be the first indication that a young star has formed planets.



when their gravitational attraction pulls them together.

Astronomers think the further growth of planetesimals into planetary embryos as large as the Moon is a runaway process. The most massive planetesimals, with their stronger gravities, gobble up smaller bodies. In as little as 100,000 years, a nascent solar system might contain a swarm of hundreds of lunar-mass planetary embryos moving on nearly circular orbits.

After this comes a longer-lasting phase in which embryos "compete." As these objects interact with one another's gravity over many orbits, their initially circular orbits become increasingly elliptical. Once these orbits grow eccentric enough, planetary embryos collide and merge into even larger bodies. This final phase of growth, which takes tens of millions of years, is punctuated by incredibly energetic impacts between planet-size bodies colliding at speeds up to 22,000 mph (36,000 km/h).

In our solar system, such a collision stripped most of the rocky material from the protoplanet that became Mercury. The crash left Mercury with an iron-rich core and little else. Closer to home, a Mars-size embryo struck the early Earth off-center. This created a spray of debris trapped in Earth orbit that later accreted to form the Moon.

Detailed models of these processes give astronomers a reasonably complete picture of how terrestrial planets formed. Planet-building appears to be an intrinsically chaotic process, one in which the final outcome is highly uncertain until the last major collision occurs and the surviving planets are on stable orbits.

The 1992 discovery of Earth-mass planets orbiting the pulsar PSR B1257+12 was the first confirmation of this accumulative process. In the case of the pulsar, the planets appear to have formed out of debris from the stellar explosion. That the process could work in such a hostile environment made scientists optimistic it could work in the comparatively benign dust disk around a young star.

Super-Earth or ice giant?

Recent discoveries lend further support to this basic picture. The race is on to find

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Alan P. Boss *is an astrophysicist at the Carnegie Institution of Washington and the author of* Looking for Earths: The Race to Find New Solar Systems *(Wiley, 1998).*

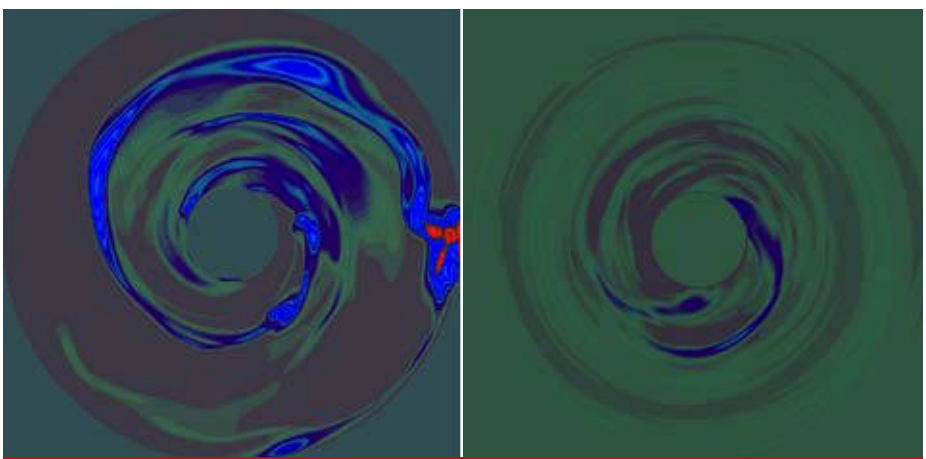
planets like Earth. So far, astronomers have identified extrasolar planets with inferred masses as low as 5.5 Earths circling around normal stars. But while the pulsar planets are probably composed of rock and metal, the "super-Earths" could be made of ice — a composition closer to that of the ice-giant planets Uranus and Neptune than to Earth or Venus. Several of the newfound planets have masses between 10 and 20 times Earth's — right in the ice-giant range.

Eventually, astronomers will find a multi-Earth-mass planet that, from our perspective, passes in front of its star. Such transits dim the star's light by an amount that depends on the planet's diameter. Thus, astronomers will be able to estimate the planet's density. If the density is high — similar to Earth, the densest planet in the solar system — astronomers will be sure they've found a super-Earth. If, however, a transiting exoplanet is half Earth's density, then the world may contain a large fraction of water, ammonia, or carbon dioxide — it's an ice giant. Either way, the presence of multi-Earth-mass planets orbiting close to their stars seems to prove that the collisional accumulation process responsible for creating the solar system's innermost planets also operates elsewhere in our galaxy.

Moreover, planets appear to be an almost inescapable result of the processes occurring in a protoplanetary disk. Because such disks commonly accompany young stars, astronomers expect habitable worlds like our own are frequent denizens of our galaxy. NASA's Kepler Mission, currently scheduled for launch in 2008, will be able to detect the transits of dozens of earthlike planets and will provide the first direct estimate of how common such worlds really are. NASA's Space Interferometry Mission PlanetQuest (SIM PlanetQuest), currently scheduled for launch after 2014, will be able to detect the tiny wobbles induced in stars by the presence of multi-Earth-mass planets.

Astronomers will need telescopes capable of directly detecting and studying earthlike planets. Both NASA and the European Space Agency (ESA) have planned such space telescopes, but it's unclear whether these projects will survive tightening budgets.

ASTRONOMERS NOW are finding planets with masses between those of Uranus and Neptune. In May, Swiss researchers announced three such worlds orbit the Sun-like star HD 69830. These planets could be either gas giants or enormous rocky worlds. In 2005, a study of the same star using the Spitzer Space Telescope turned up a possible asteroid belt. ESO



MAKING JUPITER-MASS clumps in a protoplanetary disk happens more readily in a binary star system (left) than within a disk orbiting a single star (right). Both of these computer-simulation images show the disks after about 300 years of evolution. Both show a region around the protostar equaling about 20 times Earth's average distance from the Sun. The young protostar lies unseen at the center of each disk. Colors represent the density of gas and dust in the disk's midplane. Blue and orange show the highest-density regions, where planet-forming clumps exist.

ALAN P. BOSS, CARNEGIE INSTITUTION OF WASHINGTON

Making gas giants

While astronomers largely agree on ideas about exo-Earth formation, the situation with gas giants is more contentious. There's little agreement how Jupiter, Saturn, and the roughly 150 gas-giant exoplanets formed. Two entirely different theories, as well as a continuum of intermediate possibilities, exist.

One group believes gas giants form "bottom up" in the outer part of a protoplanetary disk, where cooler temperatures let volatile substances like water and ammonia coexist as solid particles with rock and metal. The addition of the icy particles in the disk boosts the number of potential planetary building blocks by 2 or 3 times. Orbits in the outer disk enclose a larger area, too. Because of these effects, theorists believe planetary embryos with several Earth-masses could grow in less than about 10 million years — much faster than the inner disk's final growth phase.

Once the embryos reach masses of roughly 5 to 10 Earths, they're so massive that their gaseous atmospheres are no longer stable; the embryos rapidly attract more gas from the disk. The solid core then quickly accretes hundreds of Earth-masses of gas and dust, yielding a final planet with a solid rock/ice core buried beneath a massive

PROTOSTARS appear in RCW 49, which is one of the Milky Way's busiest birthing grounds. In this false-color Spitzer Space Telescope image, RCW 49's older stars appear at the cloud's center in blue, gas filaments in green, and tendrils of dust in pink. Speckled throughout the dust clouds are more than 300 stars not previously seen. The nebula lies 13,700 light-years away in Centaurus. NASA/JPL-CALTECH/E. CHURCHWELL, UNIVERSITY OF WISCONSIN

envelope of hydrogen and helium gas. Such "core accretion" is the most popular mechanism for giant-planet formation, by far. One reason: It uses the same collisional accumulation process astronomers agree must occur in the disk's inner regions.

A "top-down" approach to giant-planet formation lies at the other extreme. In this view, the disk's gas itself begins the process, without requiring a solid core. Most of the protoplanetary disk's mass resides in hydrogen and helium gas — solid particles make up only 1 percent. In recent core-accretion models, astronomers assume the disk has about 10 percent of the star's mass; this allows gas giants to form quickly.

But such a massive disk is likely to be on the verge of gravitational instability. This means any lumps in the gas can grow by pulling more gas onto themselves through their own gravitational forces. In a few orbital periods, this runaway process leads to the formation of spiral arms much like those in spiral galaxies. Multiple spiral arms form and collide with each other, and, where they intersect, transient clumps of high-density gas appear within 1,000 years. If these clumps are dense and cool enough, they'll contract to higher densities. They're on the path to becoming gas-giant protoplanets. Astronomers refer to this top-down approach as the disk-instability mechanism.

Dust particles within a dense clump begin to coagulate and fall toward the protoplanet's center. This process takes place in 100,000 years or less — much faster than it will take the clump itself to contract to planetary densities. A Jupiter-mass protoplanet could then end up with a rock/ice core of up to about 6 Earth-masses without accreting any solids. Disk instability is the dark-horse candidate in the gas-giant-formation sweepstakes. It's championed by only a few wild-eyed theorists who like long odds — including myself.

Between these two extremes lie hybrid mechanisms. They make giant planets by combining collisional accumulation of solids and spiral arms in an unstable gas disk. Spiral arms have the desirable trait of creating drag forces on solid particles. This pulls the particles toward the arms' centers, where they're more likely to collide and grow.

The test's the thing

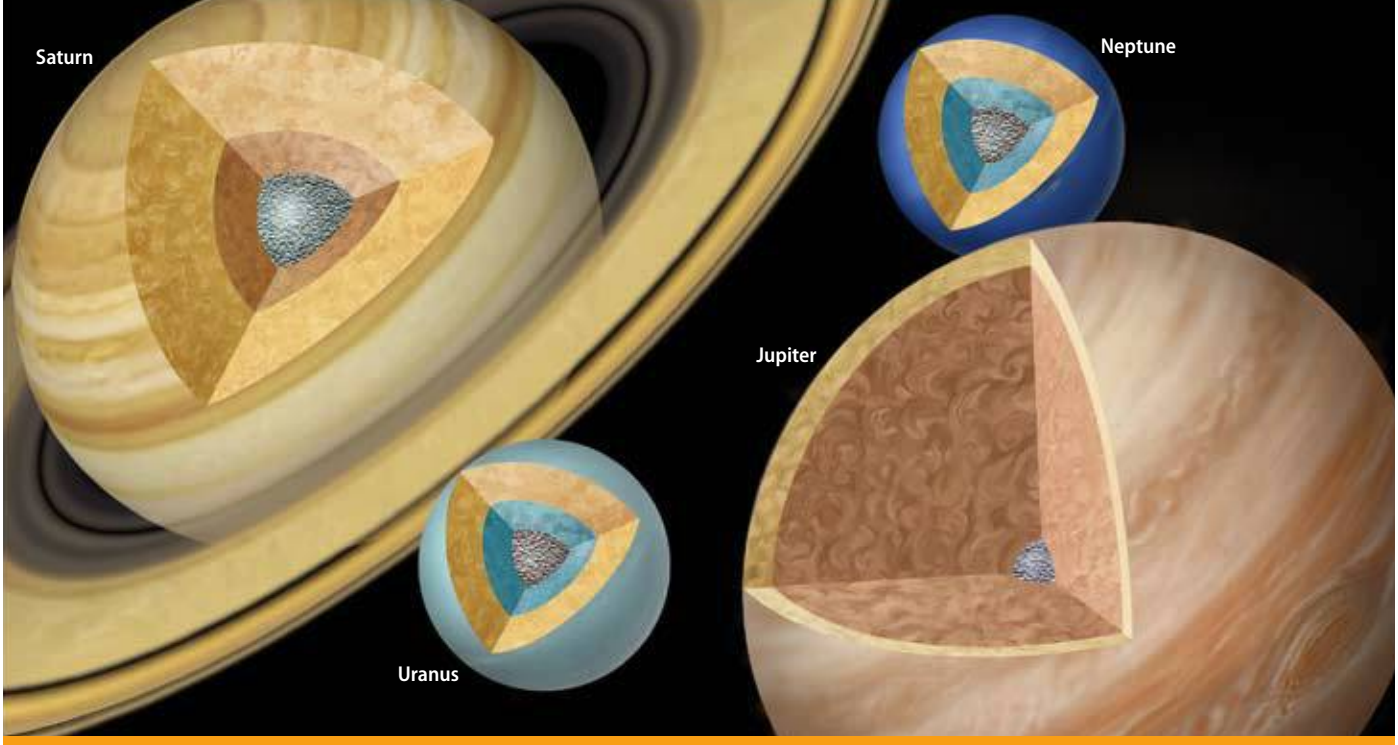
Astronomers developed the core-accretion mechanism several decades ago. At that time, theorists believed Jupiter, Saturn, Uranus, and Neptune contained solid cores of about 15 Earth-masses. New models of Jupiter's interior suggest it possesses a core smaller than 3 Earth-masses. If correct, Jupiter couldn't have formed by core accretion unless it formed with a much bigger core than it now has.

Can the cores of giant planets erode over time? If so, then core masses will lose much of their importance in discriminating between formation scenarios. Saturn appears to have a core mass of 15 to 20 Earths. Why didn't Saturn's core erode? And why, with its larger core, didn't Saturn become the solar system's most massive planet?

The disk-instability theory tries to explain the core masses of Saturn, Uranus, and Neptune. In this model, each planet began with a mass of around 3 Jupiters, which led to cores of less than 18 Earth-masses. Astronomers think the solar system formed in a crowded stellar nursery similar to what we see today in the Orion Nebula. The ultraviolet light of nearby massive stars boiled away any excess gas from Saturn, Uranus, and Neptune. This prevented them from outgrowing Jupiter.

Astronomers lack much in the way of limits for extrasolar gas-giant cores. One transiting planet (HD 149026b) appears to have a 70-Earth-mass core surrounded by a 20-Earth-mass gaseous envelope. On the other hand, the first observed transiting exoplanet, HD 209458b, may not have a solid core at all; similar models can explain the sizes of other transiting planets. For the moment, such observations are little help in narrowing down how giant planets form.

Spectroscopic surveys of extrasolar planets indicate that about 10 percent of Sun-like stars have gas-giant planets between 0.1 to 10 Jupiter-masses and orbital periods of a few years or less. Another 10 percent or so of these stars may host longer-period giant planets with orbit sizes similar to Jupiter's. While the census is not yet complete, it seems many nearby stars harbor gas-giant planets. To explain the prevalence of giant planets, astronomers need at least one robust formation mechanism.



JUPITER, the solar system's most massive planet, may have a core only 3 times Earth's mass. Instead, Saturn has the largest core (15 to 20 Earths), and planetary scientists think the cores of Uranus and Neptune best Jupiter's, too. Did Jupiter's core erode after it formed? Or did proto-Jupiter suddenly lose core mass even as it gathered gas? Planetary scientists want to know. *ASTRONOMY:* ROEN KELLY

Core accretion seems to require several million years or more to form a gas giant. Yet, observations of young stars suggest a disk's gas disappears in a few million years or less. The core-accretion method may be too slow a process to form gas-giant planets in large numbers.

On the other hand, disk instability is fast enough to form a gas giant in even the shortest-lived protoplanetary disk. Most stars form in clusters containing high-mass, luminous stars. Energetic radiation and strong stellar winds from these stars likely evaporate disk gas rapidly. The fact that we detect so many gas giants suggests disk instability is necessary.

The lower the mass of the host star, the more acute core accretion's time-scale problem becomes. M-type dwarf stars rarely form gas giants by core accretion. Disk instability, however, is rapid enough that M dwarfs can build gas giants in abundance. While the frequency of gas giants around M dwarfs appears to be less than that around G dwarfs like the Sun, it isn't zero, and these planets may require the disk-instability mechanism.

Spectroscopic surveys have focused on metal-rich stars, as studies show these stars harbor more short-period planets than do metal-poor stars. This is commonly taken as proof of core accretion's dominance: Metal-rich stars presumably had metal-rich disks, which led to more solids that could serve as building blocks for giant-planet cores. However, higher metal content is also associated with faster inward migration of giant planets after they open gaps in the disk gas. This effect could explain part of the metal-content correlation. We would expect to find giant planets on short-period orbits around metal-rich stars.

Disk instability seems able to form gas giants in both metal-poor and metal-rich disks. A key test will be to see if metal-poor stars host long-period gas giants. At least one such system exists: a Jupiter-mass world orbits a pulsar and its white-dwarf companion in the globular cluster M4. The dwarf has 20 to 30 times less metal than the Sun.

DISK INSTABILITY IS the dark horse in the gas-giant-formation sweepstakes.

Some giant planets seem to form in less than a million years. Two examples: the imaging of a possible Jupiter-mass protoplanet around the young star GQ Lupi, and the spectroscopic evidence for gaps caused by a giant planet in the disks of CoKu Tau 4 and other young stars found by the Spitzer Space Telescope. Core accretion doesn't seem able to form planets this quickly.

Choices, choices

Neither core accretion nor disk instability is a completely developed theoretical mechanism. Both approaches leave major questions unanswered. For instance, how does planetary migration affect core accretion? How fast can disk instability cool a protoplanetary disk? Ongoing investigations are addressing these problems.

Perhaps both mechanisms occur in the galaxy, but some environments favor one over the other. While the impetus for extrasolar-planet studies remains the search for habitable worlds, this search also will help us learn more about extrasolar gas giants.

Ground-based facilities like Chile's Atacama Large Millimeter Array and the planned Giant Segmented Mirror Telescope will work with space-based instruments like NASA's Spitzer, Kepler, and the future SIM PlanetQuest and James Webb telescopes. These studies will provide the observational tests needed to determine whether theoreticians' amusements have a place in the real universe.

ONLINE EXTRA Come to www.astronomy.com/toc to see simulations of planetary migration and disk instability.

EXTRASOLAR PLANETS

SPECIAL REPORT

Planets without suns

Isolated giant planets, unbound to any star, may be the Milky Way's most common worlds.

/// BY MARÍA ROSA ZAPATERO OSORIO

Recent deep explorations of some of the Milky Way's youngest star-forming regions have provided a new twist to studies of planets outside the solar system. Astronomers have uncovered objects with masses similar to the numerous giant planets found orbiting other stars. But these newfound objects travel alone, unattached to a sun for light or warmth. They float freely among the stars.

Scientists don't yet even agree on what to call these bodies. They're variously referred to as free-floating planets, planetary brown dwarfs, isolated planetary-mass objects, cluster planets, super-planets, or "planetars."

These intriguing objects are the lowest-mass members of the star clusters in which they formed. A few may be captured into orbit around stars and create planetary systems indistinguishable from true solar systems. Dynamical interactions with cluster stars may eject others into the Milky Way at large. The remainder will travel within their home star clusters until the clusters themselves disperse into the Milky Way's disk.

The existence of these isolated planetary-mass objects challenges the current knowledge of stellar and planetary formation. Did they form out of the dust and gas in protoplanetary disks surrounding newborn stars? Or do they represent a natural extension of the star-formation process to extremely low masses?

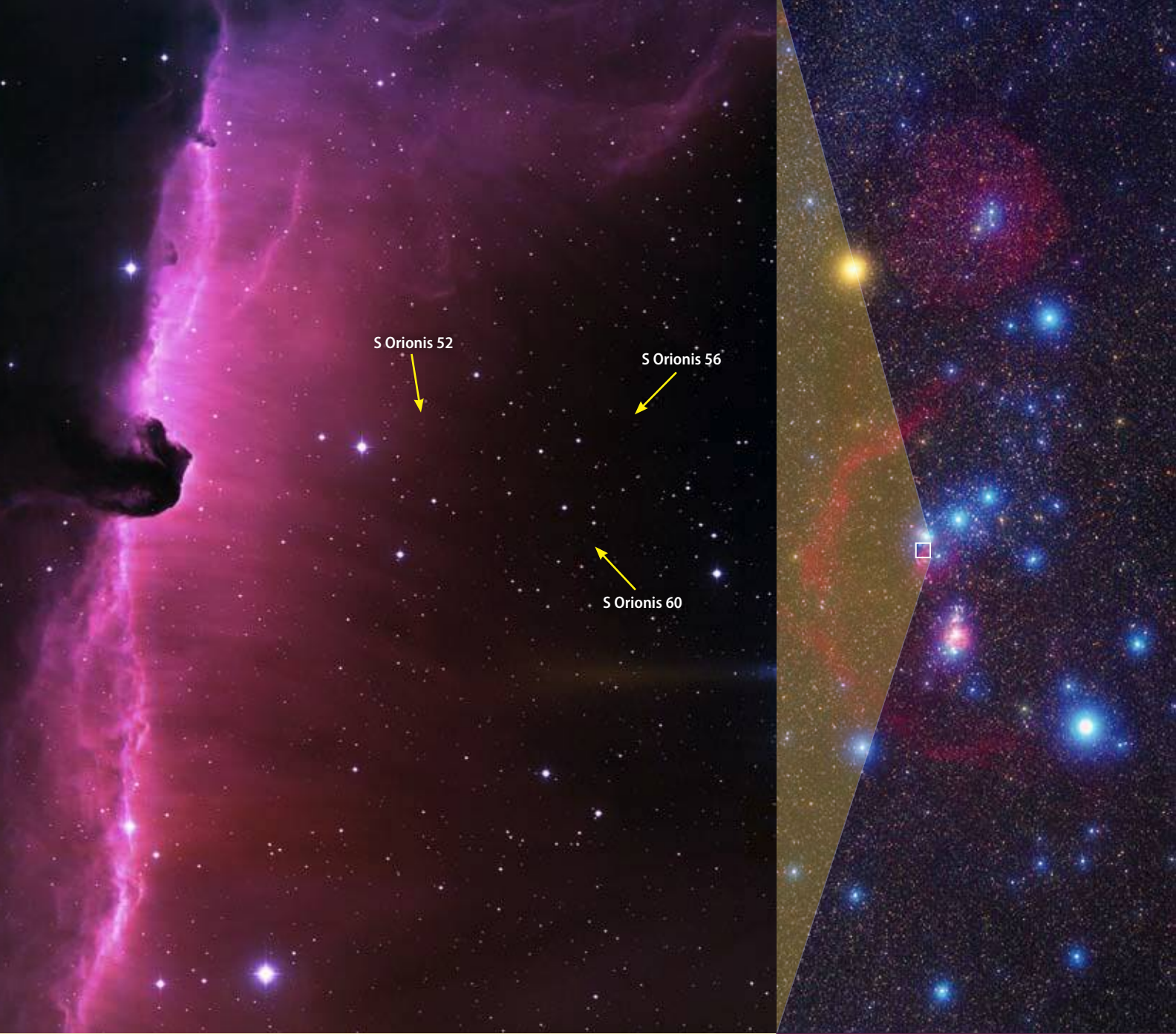
María Rosa Zapatero Osorio *is an astronomer at the Institute for Astrophysics in La Laguna, Tenerife, in Spain's Canary Islands.*

Family ties

The atmospheres of free-floating planets closely resemble those of brown dwarfs and the smallest stars. In fact, brown dwarfs are the big sisters of free-floating planets. Brown dwarfs span a mass range of 12 to 75 times that of Jupiter, the solar system's largest planet. Planets have masses smaller than 12 Jupiters, while normal stars are larger than 75 Jupiters.

These limits aren't arbitrary, but are related to what goes on inside each class of object. Stars are massive enough to attain the high core temperatures required to undergo hydrogen fusion over a sustained period. Brown dwarfs are too light to fuse ordinary hydrogen, but they're massive enough to ignite the nuclear fusion of deuterium, a less common hydrogen isotope. All brown dwarfs deplete their deuterium supply in less than 30 million years. No longer generating energy, they start to cool off like planets.

Planets, on the other hand, have cold interiors incapable of producing any nuclear reaction at all. So, planets and brown dwarfs do not shine in the same manner as stars. Recent imaging and spectroscopic observations indicate brown dwarfs and isolated planets share many characteristics with both low-mass stars and giant exoplanets. Indeed, these smaller



bodies can yield crucial insights into stellar and planetary formation.

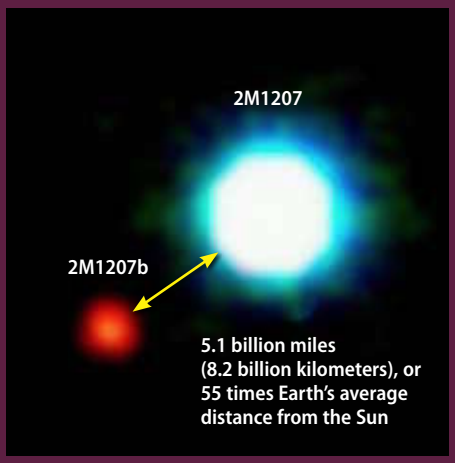
Young, red, and dim

Having searched visible and near-infrared images collected with ground- and space-based observatories, astronomers identified dozens of isolated planets in the Orion and Chamaeleon I star-forming regions. The same methods reveal hundreds of brown dwarfs — both young ones in many star-forming regions and old ones closer to the solar system. Brown dwarfs and free-floating planets both show prominent red colors and low brightnesses that distinguish them from other cosmic sources.

All of the isolated planets known to date, as well as many of the brown dwarfs, are infants, with ages less than 5 million years. That's 1/1,000 the age of the solar system. Scientists derive the objects' masses by comparing observed properties (age, distance, brightness, and color) to evolutionary models, which predict the objects' surface temperatures and luminosities as functions of their ages and masses. Astronomers find young brown dwarfs throughout the entire mass range of 12 to 75 Jupiters, while the free-floating planets in Orion have masses ranging from 3 to 12 Jupiters.

The most successful planet-hunting technique indirectly detects the presence of

ASTRONOMERS discovered the first isolated planets floating through Orion's Sigma (σ) Orionis cluster near the famous Horsehead Nebula. The nebula is a dark molecular cloud about 1,600 light-years away that lies in front of a star-forming region marked by the strip of glowing gas. Arrows show where astronomers found three cluster members with confirmed masses between 5 and 15 times that of Jupiter. HORSEHEAD: T. A. RECTOR/NOAO/AURA/NSF AND THE HUBBLE HERITAGE TEAM/STScI/AURA/NASA; ORION: BILL AND SALLY FLETCHER



◀ **A BROWN DWARF** harbors a planetary-mass object in what appears to be a strange, cold solar system. The young 25-Jupiter-mass brown dwarf 2MASSWJ1207–393254A (2M1207, for short) is located in the young TW Hydrae stellar association. In 2005, astronomers confirmed that a 5-Jupiter-mass gas-giant planet (2M1207b) is traveling through space with the dwarf. Scientists don't fully understand how the pair formed. ESO

NATURE IS SHOWING us a continuum of planetary-mass bodies, some isolated and some bound to stars.

Jupiter-mass planets by the slight wobbles they impart to their stars. The discovery of planets without stars and the study of the lowest-mass population of young star-forming regions dovetails with the growing catalog of exoplanet systems. Nature is showing us a continuum of planetary-mass bodies, some isolated and some gravitationally bound to stars.

Why do researchers look for brown dwarfs and isolated planetary-mass objects in young stellar nurseries? The youth of these objects makes them stand out. Sub-stellar objects lack a significant nuclear engine in their interiors. Theory predicts that all newly formed brown dwarfs and planets collapse under their own weight until they settle into an equilibrium between gravity and the quantum pressure exerted by the densely packed electrons deep inside them. Physics sets the size of brown dwarfs and free-floating planets as similar to Jupiter, regardless of their masses. In general, stars are much larger because their sizes are the result of a balance between the inward pull of gravity and the outward push of the energy released by hydrogen fusion.

With no important source of internal heating, brown dwarfs and planetary-mass objects evolve toward cool surface temperatures (less than 1,300° Fahrenheit [700° Celsius]) and low luminosities. Consequently, the younger these objects are, the warmer and brighter they are, which makes them easier to detect. Finding free-floating planets with ages typical of the solar system is a challenge for current facilities. Before astronomers take any pictures of isolated Jupiters this old, they'll need next-generation instruments like the James Webb Space Telescope and ground-based telescopes more than about 100 feet (30 meters) across.

There's another reason astronomers like to study young brown dwarfs and isolated planets. Learning how these objects are distributed at their birthplaces may help researchers glean details of the way stars and sub-stellar objects form.

Birth pangs

Stars form one way, while planets form in another. Astronomers say low-mass stars form when a dusty molecular cloud fragments and collapses from its own gravity. Planets, however, develop out of the debris disks surrounding newborn stars. So, which scenario explains brown dwarfs and isolated planets?

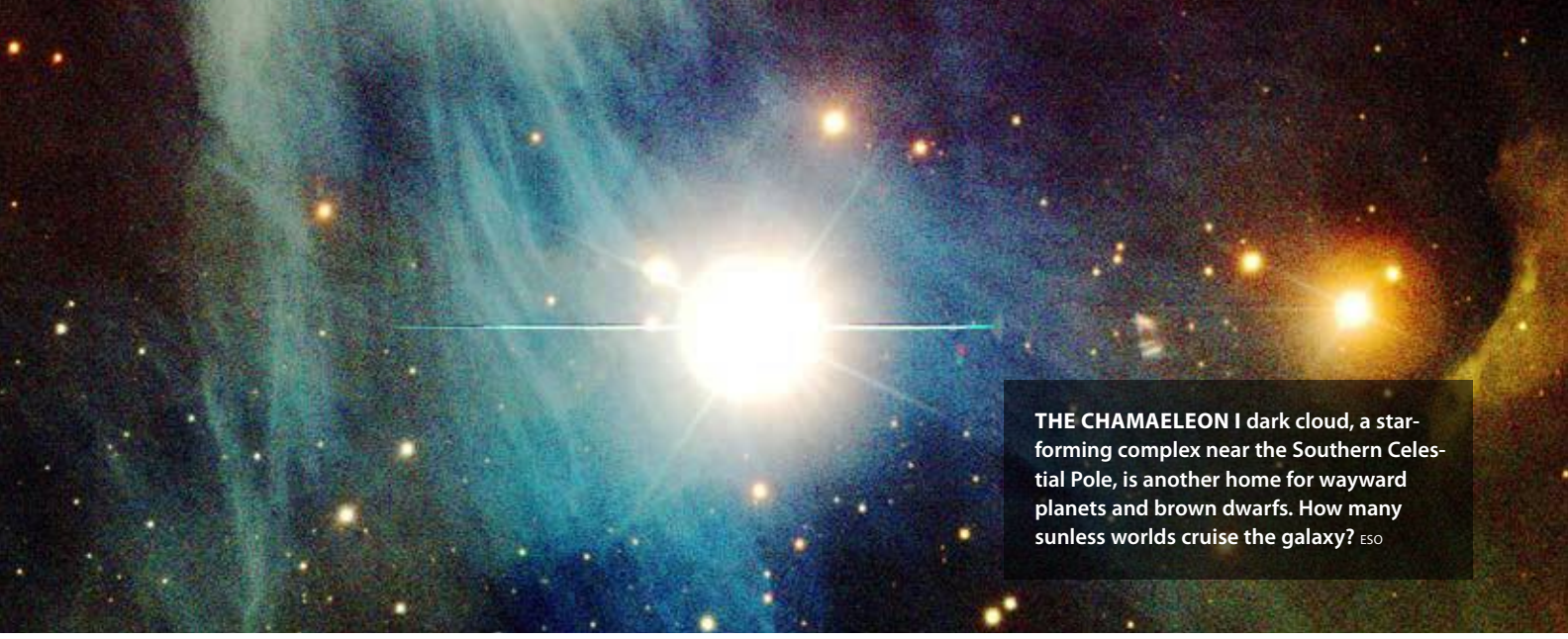
Neither model quite works. Within a molecular cloud, a sufficiently large and dense core can overcome gas pressure and collapse under its own gravity. At the temperature, composition, and density typical of cold clouds in the galaxy's disk, an individual cloud core has a minimum mass of roughly 1 Sun. The core's densest regions break into smaller clumps before a single star forms. The smallest clumps may have masses as low as 5 to 10 Jupiters.

Magnetic fields, which are always present in molecular clouds, may break the clumps into even smaller fragments, possibly pushing the minimum clump mass down to 1 Jupiter-mass. However, the effects of magnetic fields on the origins of stars and sub-stellar bodies remain unclear. The smallest fragmented clumps are likely stellar embryos embedded in the core from which they are accreting gas. Astronomers believe these embryonic stars will sweep up most of the core material to become real hydrogen-burning stars. This scenario accounts for small stars with at least 10 percent of the Sun's mass.

To explain the existence of brown dwarfs and free-floating planets, the embryos must halt their growth to full stellar size. Some theorists suggest gravitational interactions with more massive, neighboring clumps eject the smallest cores, and this results in brown dwarfs and isolated planets. By getting kicked out of the nursery so rapidly, these cores are unable to gather enough gas to become hydrogen-burning stars.

Computer simulations of this scenario predict that expelled brown dwarfs and small stars form in similar numbers. But because of their premature expulsions, sub-stellar objects lose many of the properties astronomers associate with stars. For example, brown-dwarf binaries with widely separated components would be rare, and protoplanetary disks around brown dwarfs would be truncated and short-lived.

Other ways to stunt the growth of stellar embryos exist. Collisions or close encounters with siblings may strip gas from stars as they form. Intense ultraviolet light from a nearby massive star may do this, too, or it may somehow inhibit the accretion process. These scenarios suggest the formation of sub-stellar objects depends on their environmental conditions. That is, brown



THE CHAMAELEON I dark cloud, a star-forming complex near the Southern Celestial Pole, is another home for wayward planets and brown dwarfs. How many sunless worlds cruise the galaxy? ESO

dwarfs and planetary-mass objects would be more frequent in star-forming regions containing many massive, hot blue stars.

Some models don't view brown dwarfs or isolated planets as frustrated stars. Instead, they predict sub-stellar objects form out of the direct collapse of an ultra-small cloud fragment as a result of turbulent motions within the molecular cloud. If true, brown dwarfs and stars may share common properties, such as the ability to retain a protoplanetary disk.

Building planets

Scientists believe planets gravitationally bound to a star begin with the gradual accretion of dust particles into larger bodies called planetesimals, which collide and join to form protoplanets. The growing planets soon become massive enough to attract lots of gas and dust.

Observations of young stars indicate disks around stars can last 10 million years, which sets the maximum mass for a planet formed this way at 10 to 15 Jupiters. Planets may interact with each other, as well as with the disk, resulting in planetary migration, disk instabilities, and ejections from the system. Also, the stars harboring planets may encounter young stellar neighbors, which might remove the outermost planetary objects.

All formation scenarios provide astronomers with a set of properties for these newborn objects. Researchers now are testing some of these predictions by observing young, low-mass stars, brown dwarfs, and free-floating planetary objects; other tests will have to await more advanced telescopes. Recent mid-infrared imaging data obtained with NASA's Spitzer Space Telescope reveal young brown dwarfs — from the most massive ones to those approaching the deuterium-burning mass limit of 12 Jupiters — have disks of gas and dust much the same as those around low-mass stars. The frequency and lifetime of disks around brown dwarfs and stars are similar, too. Yet, scientists know neither the full extent nor the total mass of typical sub-stellar disks.

Astronomers have also identified the telltale signs of disk material flowing into sub-stellar objects, which confirms ongoing accretion processes like those observed in stars. However, brown dwarfs do not seem to accrete as much gas as stars do.

> ISOLATED GIANT planets may be more abundant than their counterparts orbiting Sun-like stars.

The binary nature of brown dwarfs and free-floating planets can also shed new light on the subject. About 10 to 20 percent of isolated brown-dwarf binary systems have components of similar mass. Low-mass binary star systems share this trait. Interestingly, scientists also find that brown dwarfs orbiting stars are about 50 percent more likely to be binaries than isolated brown dwarfs. Any successful formation theory will need to account for these and other findings.

A detailed analysis of the stars, brown dwarfs, and free-floating planets in star-forming regions and star clusters may help astronomers disentangle one formation mechanism from another. How frequent are brown dwarfs and planetary objects as compared to stars? How are they distribution within clusters?

Ultimately, astronomers would like to nail down the mass function for these objects. The mass function relates the mass of the objects to the number that forms. It's well established that the number of stars increases with decreasing stellar mass; that is, there are many more cool and small stars than large and hot ones. Studies of stars in the Pleiades, Orion, and other star-forming regions show that brown dwarfs share the same trend. This indicates brown dwarfs are, indeed, common in the Milky Way's disk; they may even outnumber solar-type stars.

Scientists expect a few hundred brown dwarfs populate the solar neighborhood. But, to date, astronomers have identified only a few dozen of them — probably the brightest and youngest.

The number of free-floating sub-stellar bodies also seems to increase as we descend toward the planetary-mass limit. Observations suggest isolated giant planets are more abundant than their more-massive counterparts orbiting solar-type stars. Scientists first identified brown dwarfs and extrasolar planets around stars more than a decade ago. We have only just begun to understand the properties, genesis, and evolution of these surprising objects.

BY MARTIN RATCLIFFE AND ALISTER LING

OCTOBER 06

A lunar dip through the Pleiades

Get ready for an action-packed session of lunar hide-and-seek when the Moon crosses in front of the sparkling Pleiades star cluster (M45) October 9/10. Unlike the crescent Moon event last April — which was a fantastic sight through binoculars — light from the waning gibbous Moon during this crossing diminishes

the stars' light, making a telescope a necessity.

In quick succession around midnight EDT (9 P.M. PDT), you can watch a handful of bright stars disappear on the Moon's illuminated limb, and a couple of dozen stars with a range of magnitudes pop into view on the dark lunar limb. The sequence of events appears slightly different everywhere. You can find exact times for your area on the Internet at lunar-occultations.com/iota. Observers on the West Coast will need a clear northeastern horizon to experience the first half of the show.

If you're lucky, the Moon will graze one of the brighter Pleiads. You might see a star wink out and reappear several times in quick succession as mountains and valleys on the lunar limb pass it by. Astronomers at the International Occultation Timing Association (IOTA) can use your observations to refine the Moon's profile, but it's also just plain cool to watch.

All summer long, Jupiter graced the southern sky as a luminous beacon. Earth's faster orbital motion around the Sun now is leaving the king of the planets behind to get swallowed by the evening twilight glow. Because Jupiter appears so low in the sky, its image suffers greatly from turbulence in our atmosphere. We'll be lucky to see more than the two main cloud belts through a telescope.

A WAXING CRESCENT MOON PASSED in front of the Pleiades last April. This month, observers can see a waning gibbous Moon perform the same feat. JOHN GARRETT

Mercury climbs away from the Sun in early October and meets Jupiter around the 20th. Unfortunately, this is Mercury's worst apparition of the year for northern observers. Binoculars will be a must for most skywatchers. From south of the equator, this will be a beautiful event. Be patient, northerners, you'll get a turn in December.

If you're hungry for planets, think breakfast, and greet Saturn at dawn. It rises around 2 A.M. local daylight time, but conditions will be best when it lies highest in the sky. On the morning of the 16th, a waning crescent Moon joins the ringed planet and the blue-white star Regulus. Saturn's rings continue to flatten as the planet heads for its equinox in 2009, when the rings will appear edge-on.

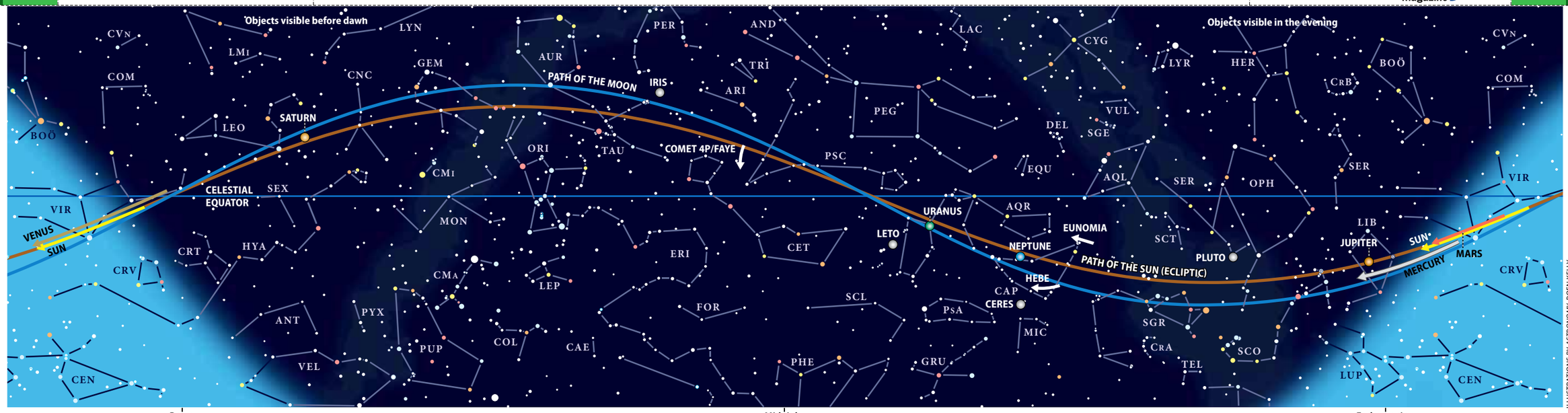
Streaking swiftly across the sky, motes of dust burn up as meteors. Although Earth constantly sweeps up interplanetary dust, our planet runs through a slightly denser trail left by Comet 1P/Halley this month. Named after the constellation from which the meteors appear to radiate, the Orionids peak October 21, timed perfectly with New Moon. Organize a group of skygazers to meet out of town, and bring lawn chairs, sleeping bags, and hot drinks to stay warm. Plan to wear winter gear — many observers are surprised at the chill of the late-night air.

About 90 minutes before sunrise, look to the east. If the sky is dark and transparent, you will see a soft glow starting near Saturn and spreading gradually toward the horizon. Sometimes called the false dawn, this is the zodiacal light: sunlight scattering off microscopic dust in the solar system's plane.

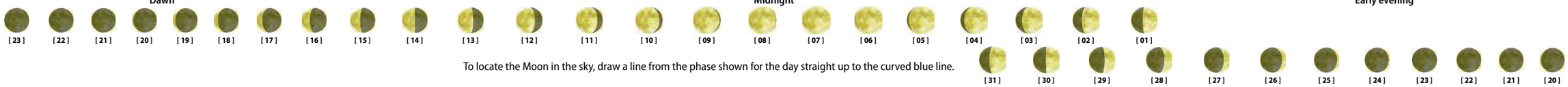
Planets this month

This map unfolds the entire night sky from sunset (at right) until sunrise (at left). Arrows and colored dots show motions and locations of solar system objects during the month.

Astronomy magazine



ILLUSTRATIONS BY *ASTRONOMY*: ROEN KELLY

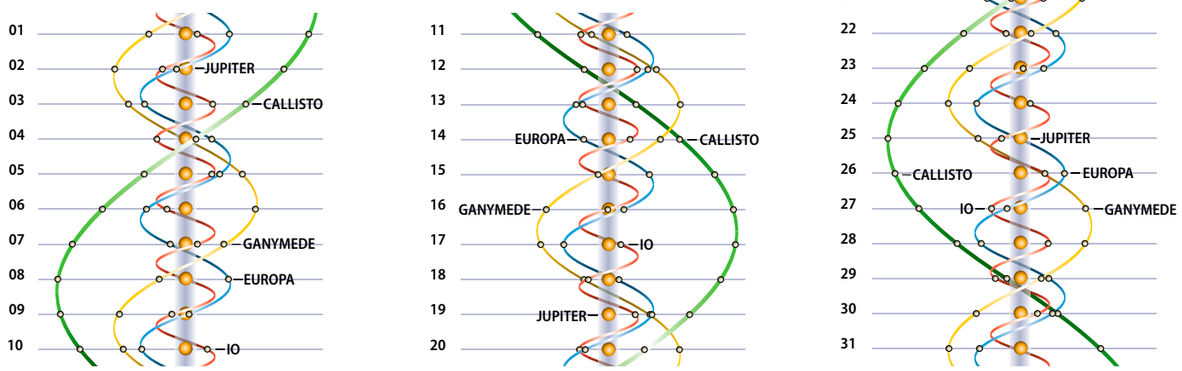


To locate the Moon in the sky, draw a line from the phase shown for the day straight up to the curved blue line.

PLANETS	MERCURY	MERCURY	VENUS	MARS	JUPITER	SATURN	URANUS	NEPTUNE	PLUTO
Date	October 1	October 15	October 15	October 15	October 15	October 15	October 15	October 15	October 15
Magnitude	−0.3	−0.1	−3.8	1.6	−1.7	0.6	5.8	7.9	14.0
Angular size	5.4"	6.4"	9.7"	3.6"	31.7"	17.2"	3.6"	2.3"	0.1"
Illumination	83%	66%	100%	100%	100%	100%	100%	100%	100%
Distance (AU) from Earth	1.241	1.045	1.714	2.603	6.229	9.638	19.313	29.608	31.620
Distance (AU) from Sun	0.467	0.440	0.721	1.608	5.386	9.161	20.085	30.052	31.184
Right ascension (2000.0)	13h43.0m	14h50.7m	13h08.8m	13h29.9m	15h15.9m	9h41.1m	22h52.0m	21h18.0m	17h36.9m
Declination (2000.0)	−12°03'	−19°15'	−5°56'	−8°55'	−17°18'	14°53'	−8°06'	−15°57'	−16°13'

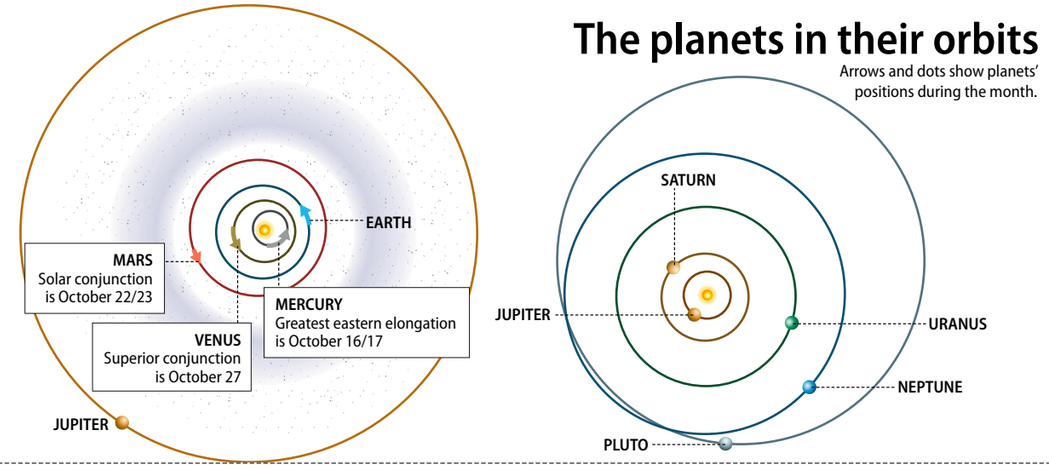
Jupiter's moons

Dots display positions of Galilean satellites at 9 P.M. EDT on date shown. South is at top to match the view through a telescope.



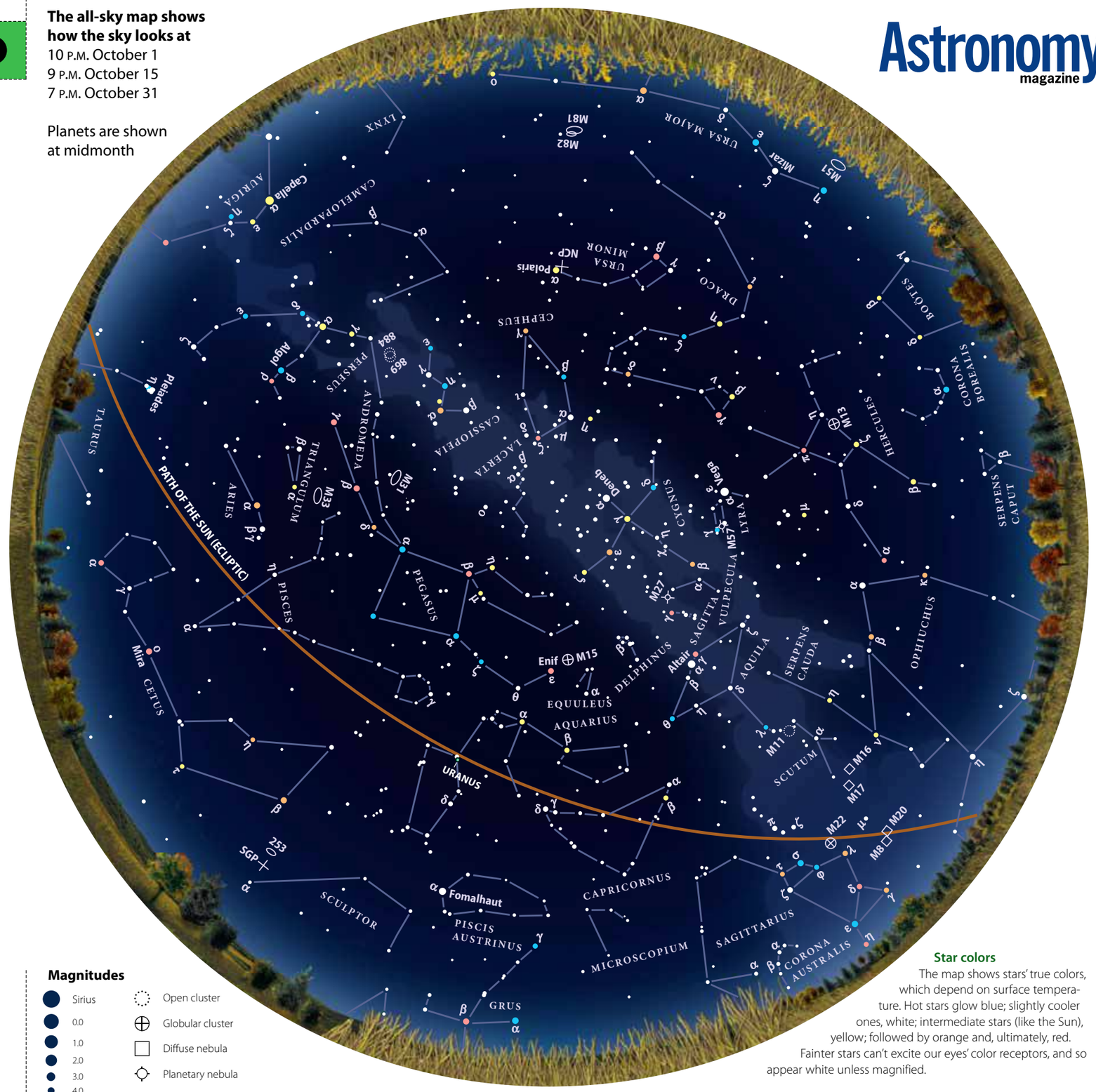
The planets in their orbits

Arrows and dots show planets' positions during the month.



The all-sky map shows how the sky looks at
10 P.M. October 1
9 P.M. October 15
7 P.M. October 31

Planets are shown at midmonth



Magnitudes

Sirius	Open cluster
0.0	Globular cluster
1.0	Diffuse nebula
2.0	Planetary nebula
3.0	Galaxy
4.0	
5.0	

Star colors
The map shows stars' true colors, which depend on surface temperature. Hot stars glow blue; slightly cooler ones, white; intermediate stars (like the Sun), yellow; followed by orange and, ultimately, red. Fainter stars can't excite our eyes' color receptors, and so appear white unless magnified.

How to use this map
This map portrays the sky as seen near 35° north latitude at times shown in the upper left corner of the page. Located just outside the map are the four directions: north, south, east, and west. To find stars above your horizon, hold the map overhead and orient it so a direction label matches the direction you're facing. The stars above the map's horizon now match what's in the sky.

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SUN.	MON.	TUES.	WED.	THURS.	FRI.	SAT.
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ILLUSTRATIONS BY *ASTRONOMY*: ROEN KELLY

03 The Moon passes 3° south of Neptune, 3 A.M. EDT

04 The Moon passes 0.5° south of Uranus, 8 P.M. EDT

06 The Moon is at perigee (222,084 miles from Earth), 10:13 A.M. EDT

Full Moon occurs at 11:13 P.M. EDT

08 Draconid meteor shower peaks

13 Last Quarter Moon occurs at 8:26 P.M. EDT

16 The Moon passes 2° north of Saturn, 10 A.M. EDT

Mercury is at greatest eastern elongation (25°), midnight EDT

19 The Moon is at apogee (252,323 miles from Earth), 5:35 A.M. EDT

21 Orionid meteor shower peaks

22 New Moon occurs at 1:14 A.M. EDT

23 Mars is in conjunction with the Sun, 3 A.M. EDT

24 The Moon passes 1.4° south of Mercury, 4 A.M. EDT

The Moon passes 5° south of Jupiter, 4 A.M. EDT

25 The Moon passes 0.4° south of Antares, 10 A.M. EDT

Mercury passes 4° south of Jupiter, 6 P.M. EDT

27 Venus is in superior conjunction, 2 P.M. EDT

28 Mercury passes 4° south of Jupiter, 10 A.M. EDT

29 First Quarter Moon occurs at 4:25 P.M. EST

30 The Moon passes 3° south of Neptune, 9 A.M. EST

ONLINE EXTRA For definitions of terms, visit www.astronomy.com/glossary.

THE DEEP SKY

The Eagle's stellar show

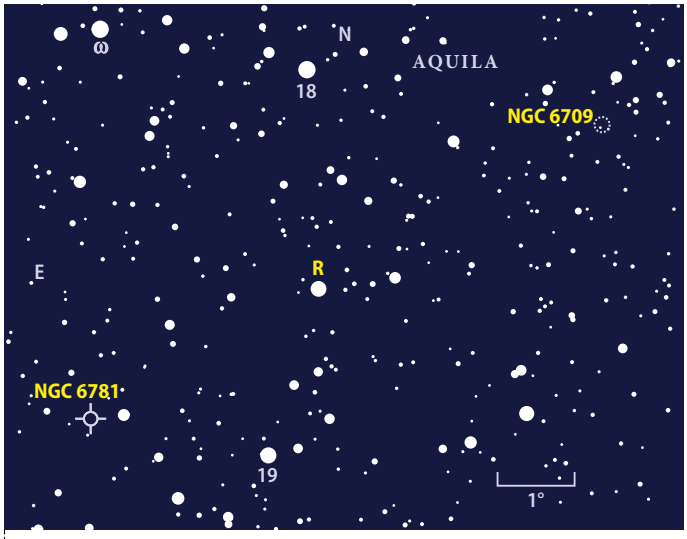
Aquila, a beautiful constellation spread-eagled across the backbone of our home galaxy, lies due south as the sky darkens. The white luminary Altair anchors the southern end of the Summer Triangle, with Deneb in Cygnus and Vega in Lyra shining higher up. Early Arabic culture shared the Greek view of Aquila as an eagle; Altair is an Arabic derivation of this mighty bird's name.

Aquila appears best under a dark sky; that's when the Milky Way is visible, and the magnificent Great Rift of interstellar dust and gas clearly splits it. Sit back in a deck chair, and slowly roam its figure through binoculars. The density of faint stars is impressive, made all the more striking by their sudden disappearance at the Rift.

From a suburban backyard, you can follow the fall of a variable star with binoculars. R Aquilae should reach its maximum brightness of magnitude 6.1 during the first half of October. To prevent confusion with other star catalogs, astronomers designated the first variable star discovered in each constellation R. Subsequent ones run through letters to the alphabet's end, then double-letter designations take over.

Astronomers don't know exactly when R Aql will be brightest or how bright it will get, and your observations can help pin it down. Hop over to aavso.org on the web, and download a free comparison chart for R Aql by typing in that name at the upper left. To estimate R's magnitude, find a nearby star equal to it, or one brighter and another fainter. See how you fare compared with other observers.

Despite Aquila's decent size and position along the spine of the galaxy, it contains no Messier objects. Don't let that stop your deep-sky observing, however. Remember, Messier had a 3-inch scope of less-than-stellar quality — you may well have something better.



ASTRONOMY: THEO COBB

AQUILA HARBORS MANY MILKY WAY
sights, including variable star R Aql, open cluster NGC 6709, and planetary nebula NGC 6781.

A delightful star cluster on Aquila's western side is NGC 6709. It sparkles across 15' of sky (half the Moon's apparent diameter), with a total magnitude of 6.7. Dozens of stars, the brightest of which shines at magnitude 9.0, contribute to the glow visible through binoculars. A fanciful Greek letter lambda (λ) springs to mind thanks to the cluster's curving star chains.

Cosmic bubble

When a star like the Sun enters into old age, it gently puffs off its outer envelope of gas. This allows the white-hot central ember to fluoresce the outflow into visibility. Aquila is home to dozens of these so-called planetary nebulae, which often resemble ghostly versions of Jupiter or Uranus.

NGC 6781 appears roughly circular, almost 2' across, and glows at magnitude 11.4. If you own a nebula filter, or a light-pollution filter, NGC 6781 will appear to jump out from the background. Such an observation is easy with a small scope from a dark sky. Give it a try from your backyard, too — you may be surprised at what you can see with the help of this technological marvel.

THE SOFT, ROUND DISK OF NGC 6781
glows at magnitude 11.4 and looks typical for a planetary nebula.

JOE GONZALEZ/JEREMY BUMGARDNER/DEVIN MAGLICK/ADAM BLOCK/NOAO/AURA/NSF

Martin Ratcliffe *is the former president of the International Planetarium Society.* **Alister Ling** *is a meteorologist for Environment Canada.*

THE PLANETS

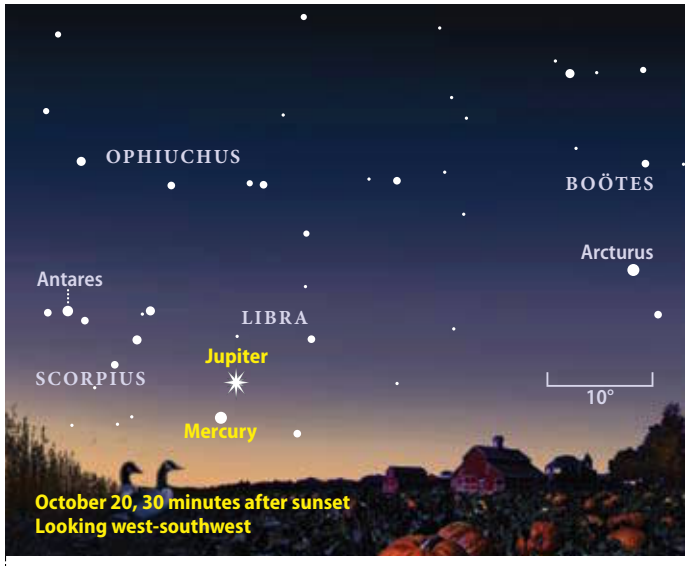
Saturn returns before dawn

Mercury and Jupiter appear briefly in the twilight sky after sunset this month. The challenge will be in spotting the fainter one, Mercury, as it hugs the southwestern horizon. Fortunately, brilliant Jupiter will guide you. Both Uranus and Neptune are on hand to give binocular viewers a modest challenge on these cool fall evenings. Early morning brings Saturn into view — standing high in the east before dawn.

Mercury reaches greatest elongation October 16/17, when it lies 25° east of the Sun. Normally, such an event signifies relatively easy viewing of the solar system's innermost planet. Not so this time. Mercury, like all planets except Pluto, always stays close to the plane of the solar system, or ecliptic. During October, the ecliptic makes a shallow angle to the western horizon in early evening. This means Mercury remains low after sunset and sets soon after. Fortunately, the much brighter planet **Jupiter** lies along the same line of sight, and it acts as a handy guide to spying Mercury.

Try looking for Mercury October 18, when it lies 4° directly below Jupiter. Flanking the two planets are Antares, standing low in the southwest, and Arcturus, somewhat higher than Antares above the western horizon. The planetary pair lies closer to the horizon than either star. Thirty minutes after sunset, Mercury stands a mere 3° high in the southwest, and Jupiter is double that altitude. You'll need transparent skies and a flat, unobstructed horizon to glimpse Mercury.

Jupiter proves much easier to spot because it's significantly brighter, shining at magnitude –1.7. Mercury appears 4 times fainter, at magnitude –0.1. The inner planet shines a bit brighter earlier in the month. On October 12, for example, it glows at magnitude –0.2 and stands 8° to Jupiter's lower right. From the Southern Hemisphere, where the ecliptic now makes a steep angle to the evening twilight horizon, Mercury and Jupiter stand high in the west after sunset.



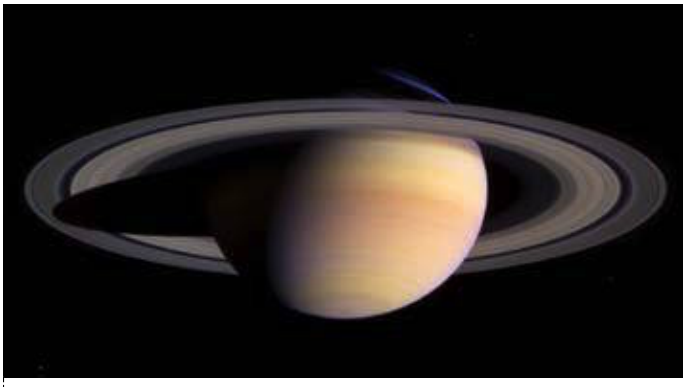
ASTRONOMY: THEO COBB

JUPITER AND MERCURY SWING LOW
in the western twilight this month, their final hurrah before disappearing into the Sun's glare.

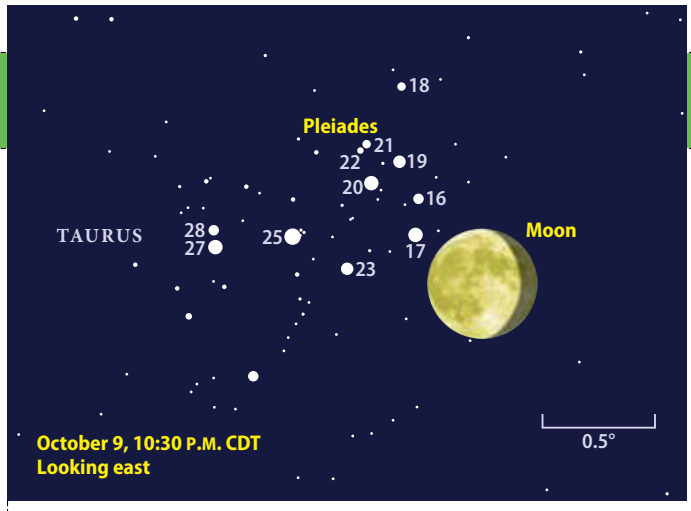
Although Jupiter usually shows lots of detail through a telescope, don't expect much this month. Turbulence in Earth's atmosphere typically ruins the view of low-altitude objects. A waxing crescent Moon joins Mercury and Jupiter the evening of October 24. The Moon then lies 8° to Mercury's left (and 8° to Antares' lower right) and sets an hour after sunset.

By midevening, the stars of Capricornus lie due south and at peak altitude. Binoculars will let you pick out the interloping planet **Neptune**. The eighth planet glows at magnitude 7.9 and lies approximately midway between Iota (ι) Capricorni and 29 Cap. Another star lies in Neptune's vicinity, but it's a magnitude brighter than the planet and shouldn't cause confusion. In fact, you can use this star to track Neptune's motion.

Grab a pencil and notepad, and mark the positions of all the objects visible through binoculars between 4.3-magnitude Iota Cap and 5.3-magnitude 29 Cap — then jot down the time and date. Repeat this process over a couple of nights, and you'll easily notice Neptune's motion. A digital camera with a zoom lens can perform the same feat: Make a 5-second exposure each night with the camera's ISO speed setting at its highest value.



MAGNIFICENT SATURN CLIMBS HIGH
into the morning sky this month, providing exquisite views to those with small telescopes. NASA/JPL/SSI



ASTRONOMY: THEO COBB

THE PLEIADES (M45) RECEIVES A VISIT from the Moon October 9/10. A telescope will show individual stars winking out on the lunar limb.

Telescopes show little of Neptune beyond its tiny blue-gray disk. Even though it's 4 times Earth's diameter, Neptune lies 2.75 billion miles away and so appears only 2.3" across.

Next find Lambda (λ) Aquarii, a 3.7-magnitude star located midway between Markab, the lower-right star in the Great Square of Pegasus, and Fomalhaut, the brightest star in Piscis Austrinus. Lambda has a neighbor this month: **Uranus**.

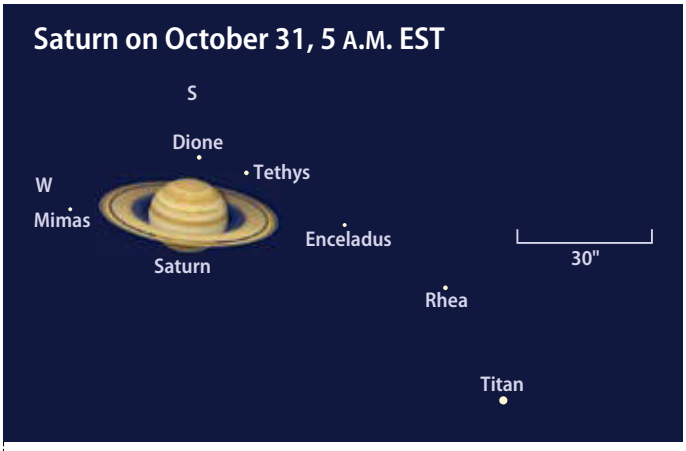
The seventh planet lies within a single Moon-width of Lambda the first half of the month. Glowing at magnitude 5.8, Uranus shows up easily in binoculars and even can be glimpsed without optical aid from a dark-sky site. Uranus passes due south of Lambda October 8/9 and continues to wander westward the rest of the month. The bright star's proximity makes tracking Uranus' motion a cinch.

As with Neptune, a telescopic view of Uranus offers distinct color in a small package. Uranus' disk measures 3.6" across and shows up readily in the smallest scope. The planet's blue-green hue makes a nice contrast with Lambda Aquarii's reddish glow.

Everyone's favorite planet, **Saturn**, rises around 3 A.M. local daylight time in early October and, given the switch to standard time at month's end, it comes up by 12:30 A.M. October 31. Saturn lies in Leo the Lion 7° from that constellation's brightest star, Regulus. A waning crescent Moon passes just 2° north of Saturn the morning of October 16.

Saturn shines at magnitude 0.6, exactly twice as bright as Regulus. The planet looks great through any telescope — all you have to do is bring it to a sharp focus. Saturn's disk spans 17" in mid-October, while the rings stretch 39" across. You should have no trouble seeing the dark Cassini Division, which separates the outer A ring from the brighter B ring.

Dozens of moons orbit Saturn, and an impressive handful come to light in small scopes. Titan is bigger and brighter than the others, so it shows up easiest. This 8th-magnitude moon takes 16 days to orbit Saturn. You can find it due north of the planet the morning of October 16 and due south the mornings of October 8 and 24.



SATURN'S MOONS MOVE CONSTANTLY, creating different views nightly. On October's final morning, see several moons line up east of the planet. ASTRONOMY: THEO COBB

Sometimes, the moons align in curious ways. For example, on October 31, Titan lies 1.5' northeast of Saturn while four fainter moons line up in a trail ending near the planet's south pole. See if you can spot Rhea, Enceladus, Tethys, and Dione. They glow at magnitudes 9.7, 11.8, 10.4, and 10.5, respectively.

Iapetus lies much farther from Saturn than the other bright moons. It also varies in brightness because it has a dual personality — its leading face is dark, and its trailing face is bright. This means the moon appears reasonably bright (magnitude 10.1) when it lies farthest west of Saturn; at greatest eastern elongation, however, the moon glows 5 times fainter, at magnitude 11.9.

October begins with Iapetus far east of the planet and near its dimmest. Its orbital path carries it across Saturn's rings and disk the morning of October 19, but Saturn's brilliant disk will hide it from view except through large telescopes. The following morning, Iapetus lies west of the rings as it heads toward greatest western elongation in early November.

Two planets pass on the far side of the Sun from our earthly vantage point this month. **Mars** reaches solar conjunction October 22/23. It will be a couple of months before it climbs high enough in the morning sky for us to see it. **Venus** reaches superior conjunction October 27. Because it lies inside Earth's orbit, and thus revolves around the Sun faster than our planet, Venus will reappear in the evening sky. It should become visible before year's end.

Check out the waning gibbous Moon October 9/10, when it rises close to the Pleiades star cluster (M45). During the late evening and early morning hours, the Moon occults many of the cluster's bright stars. The stars will be easier to see when they reappear from behind the Moon's dark limb. Light from the bright lunar limb will make the stars' disappearances more difficult to view. From the Central time zone, the events occur between 10:45 P.M. and 1 A.M. Exact times vary across North America, so check the International Occultation Timing Association's web site (lunar-occultations.com/iota) for local details.

Finally, don't forget to set your clocks back 1 hour October 29, as most of the United States and Canada return to Standard Time.

METEORS AND MOONS

No Moon for the Orionids

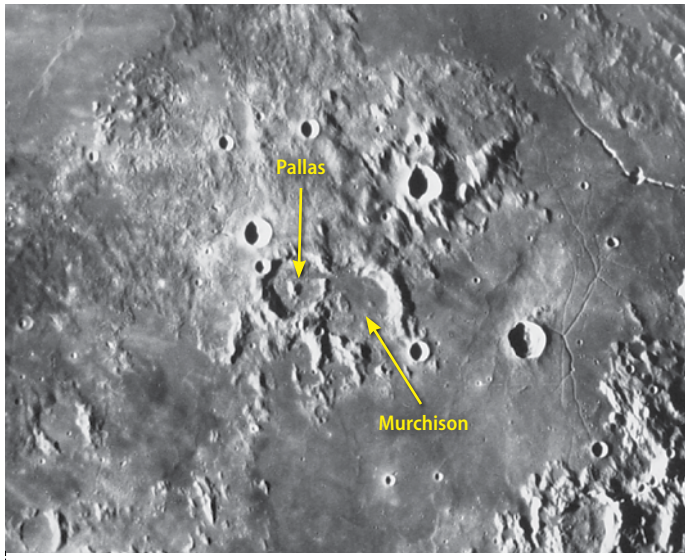
With dark skies brought to us by a New Moon, prospects look excellent for this year's annual Orionid meteor shower. The Orionids appear to radiate from a spot near the "Club" asterism in northeastern Orion the Hunter, where that constellation borders Gemini the Twins. The radiant rises before midnight and stands high in the south by 4 A.M., a full 2 hours before dawn. The shower remains active all month, beginning October 2 and ending November 7.

Meteor rates start and end with a trickle, but achieve a substantial peak October 21. (The 1993 and 1998 Orionid showers showed enhanced rates 3 to 4 days earlier, so it's worth watching the shower over a week's time centered on the maximum.) Rates can reach 20 meteors per hour, and occasionally more. The predawn hours offer the best viewing.

These meteors are among the fastest of all shower meteors, striking Earth's upper atmosphere at 41 miles per second. Many leave persistent trains — glowing tubes of ionized gas created by the dust particles burning up.

Orionid meteors derive from debris left behind by Comet 1P/Halley during its innumerable passages through the inner solar system. Earth's orbit intersects this debris trail in two places, resulting in this fine autumn shower and another good one in May called the Eta Aquarids.

THE ORIONID METEOR SHOWER
should provide a couple of dozen fast-moving meteors per hour when it peaks the morning of October 21. *ASTRONOMY:* ROEN KELLY



FROM *CONSOLIDATED LUNAR ATLAS* (UA/LPL)

LUNAR CRATER MURCHISON OVERLAPS
smaller Pallas near the Moon's center, making them tempting targets near First and Last Quarter phases.

At the Moon's nexus

A pair of overlapping and eroded craters lies almost at the center of the Moon's disk. Pallas and Murchison reside in an upland region between Mare Vaporum and Sinus Medii. With the craters' central location, sunrise occurs at First Quarter phase and sunset at Last Quarter.

Heavily eroded Murchison spans 36 miles. Its southeastern wall has been obliterated, and a fresh crater, Chladni, stands near this opening into Sinus Medii. Lava flowed into Murchison through this opening, flooding the crater's floor. To Murchison's northwest, what remains of the crater's rim is shared with Pallas, a somewhat-fresher-looking, 31-mile-wide crater with a prominent central peak. Pallas' northwestern wall has an impact crater, designated Pallas A, that disturbs its line. A larger fresh crater, named Bode, lies just northwest of Pallas.

In 1953, American amateur astronomer Leon Stuart photographed a strange flare in this region. Professionals initially dismissed this report, but images of the area taken by the Clementine spacecraft in the 1990s show a fresh, 1-mile-wide impact crater. The brief flash Stuart observed closely matches what astronomers think would have occurred during this crater's formation, so it seems likely Stuart did record the impact.

The two craters are bathed in sunlight at the beginning of October (the Sun rises over the region September 30). The Sun sets there October 13 and rises again October 29.

Iris plies the Bull's shoulder

The sparkling Pleiades star cluster (M45) is always a favorite of beginning deep-sky observers. This month, the cluster also serves as a handy guide to novice asteroid-hunters. The main-belt asteroid 7 Iris lies less than 1 binocular field northwest of M45. Glowing between 7th and 8th magnitude, Iris stands out from the background stars. Although too faint for binoculars to pull in under city lights, it's well within their reach from a dark sky during the second half of October, when the Moon's out of the way.

Wait until mid-evening, then use the chart at right to hop over to its rough position with your binoculars or scope. Apart from the pair of stars just north of the asteroid, Iris will be the brightest object in the field. Make a quick sketch of its position relative to the stellar pair and return a night or two later to see that Iris has shifted position. This is direct evidence of its place in our solar system.

John Russell Hind discovered Iris August 13, 1847, from an observatory in London. The asteroid measures about 130 miles across and has a surface reflectivity almost 4 times that of the Moon.

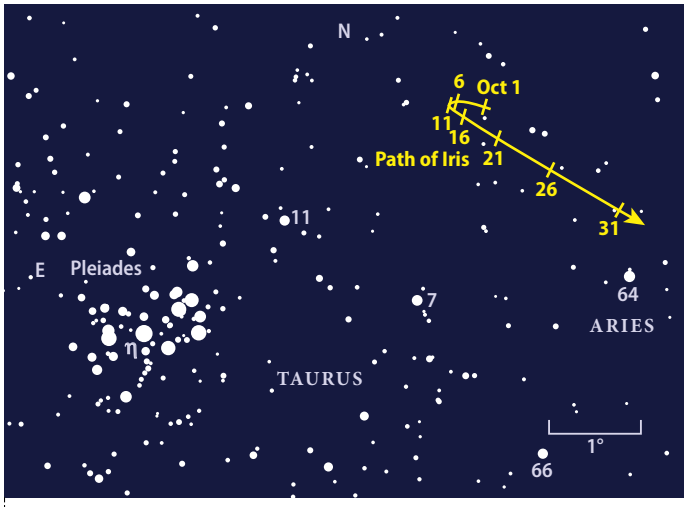
Have faith in Faye

Backyard observers love to observe comets. Bigger and brighter is always better, of course, but there's just something special about these diffuse balls of light that keeps backyard observers coming back for more. From a scientific standpoint, we know comets formed early in the solar system's history, and, therefore, contain primordial matter. Perhaps they carried the seeds of life to our little blue planet. But without a doubt, we know they can take life away with a huge impact.

The more romantic side of us connects comets with astronomers across the ages — from Edmond Halley, who discovered that some comets return to our vicinity on long elliptical paths, to Charles Messier, the "comet ferret" who sought to differentiate comets and deep-sky objects. Through our modern telescopes, we see the sky much as they did, making it easy for our thoughts to drift back in time before the age of spacecraft and astrophysics.

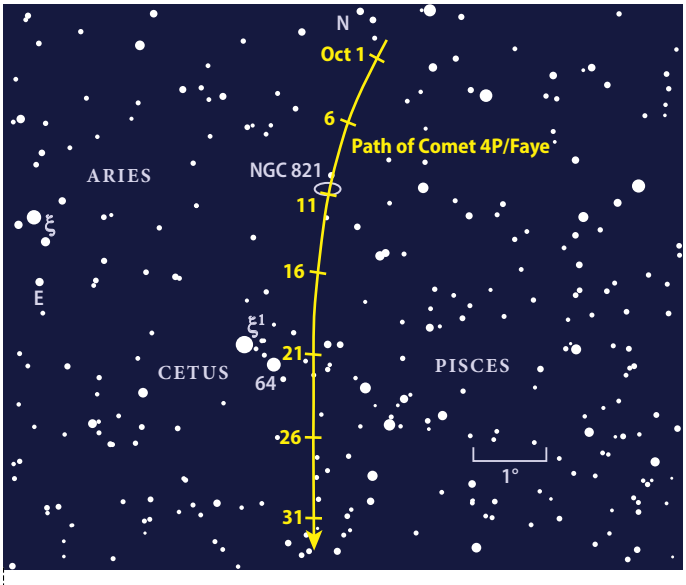
Comet 4P/Faye, one of the first comets to earn the "P" designation for being recognized as periodic, rises during the early evening in the east where Aries, Pisces, and Cetus come together. You'll get a better view if you wait until late evening, once this region climbs to a decent altitude. (The chart at left shows Faye's position at 4 A.M. EDT.) Our window of opportunity opens around October 10, but conditions improve even more after midmonth. A "Messier moment" presents itself the night of October 10/11, when Faye passes close to the background galaxy NGC 821.

The dirty snowball should glow around 9th magnitude, a moderately easy target for a 4-inch scope out in the country. Fainter and smaller than the comet, NGC 821 glows at magnitude 10.7. Although the two will look similar, notice the differences in their structures and brightness profiles.



ASTRONOMY: THEO COBB

IRIS GLOWS AROUND MAGNITUDE 7.5
as it treks along the Taurus-Aries border. Observers with small scopes should have no trouble tracking this bright asteroid.



COMET 4P/FAYE BRIGHTENS QUICKLY
this month, reaching 9th magnitude. The morning object moves slowly through Aries and Cetus. ASTRONOMY: THEO COBB

Where is life

The search for life on other planets revolves around the concept of habitability. What makes our own Sun such an excellent parent for life? Our planet has remained habitable for life for some 3.7 billion years. So, what is it that allows a planet — and its parent star — to support life?

We know life will take hold if given a chance. This is a lesson biologists have learned about Earth, where organisms prosper in ice, rock, steaming geysers, and acidic pools. We also know life changes its environment, often creating new niches for life where there were none before. Ultimately, it seems all of life's basic requirements come down to one thing: liquid water. Life needs other things, too, like construction materials (such as carbon, nitrogen, and oxygen) and an energy source (starlight, a planet's internal heat, or chemical energy). But I submit that any environment with pools of liquid water will likely have these things, too.

Part of the search for living worlds beyond the solar system involves the idea of a habitable zone around each star. This is a region where the temperature is right for the presence of liquid water on an earthlike planet. This circumstellar habitable zone is only one of the potential abodes for thriving ecosystems (see "Possible nooks for life," page 61). But at our early stage of understanding other planetary systems, the circumstellar habitable zone is the only nook we can study from afar.

LIQUID WATER flows over the surface of a giant exoplanet's moon in this artist's conception. If the giant planet orbits within its star's habitable zone, this watery moon could teem with life. LYNETTE COOK

Stability: the first obstacle

While we still have much to learn about the Sun's habitable zone, we do know Earth lies within it and has been there for billions of years. Venus — our sister planet in terms of size and mass — is 30-percent closer to the Sun than Earth and doesn't lie within the habitable zone. Venus is too hot for life and likely lost its water early in its history as oceans were boiled off by the searing sunlight.

Mars, 50-percent farther from the Sun than Earth, is colder but, nevertheless, had liquid water flowing over its surface in the relatively recent past. Mars is probably within the Sun's habitable zone, and if the planet were just a tad more massive, its gravity could hold a substantial atmosphere.

A habitable zone that lasts billions of years is an important factor in the search for planets with life. As of now, we know nothing about the presence or absence of terrestrial planets in the habitable zones of the Sun's neighbors. However, we know a lot about the stars themselves, and we can see which would make good parents.

A good parent star is one with a habitable zone that remains in the same place for billions of years. The second constraint is nothing should prevent the formation of terrestrial planets. Not all stars pass these hurdles.

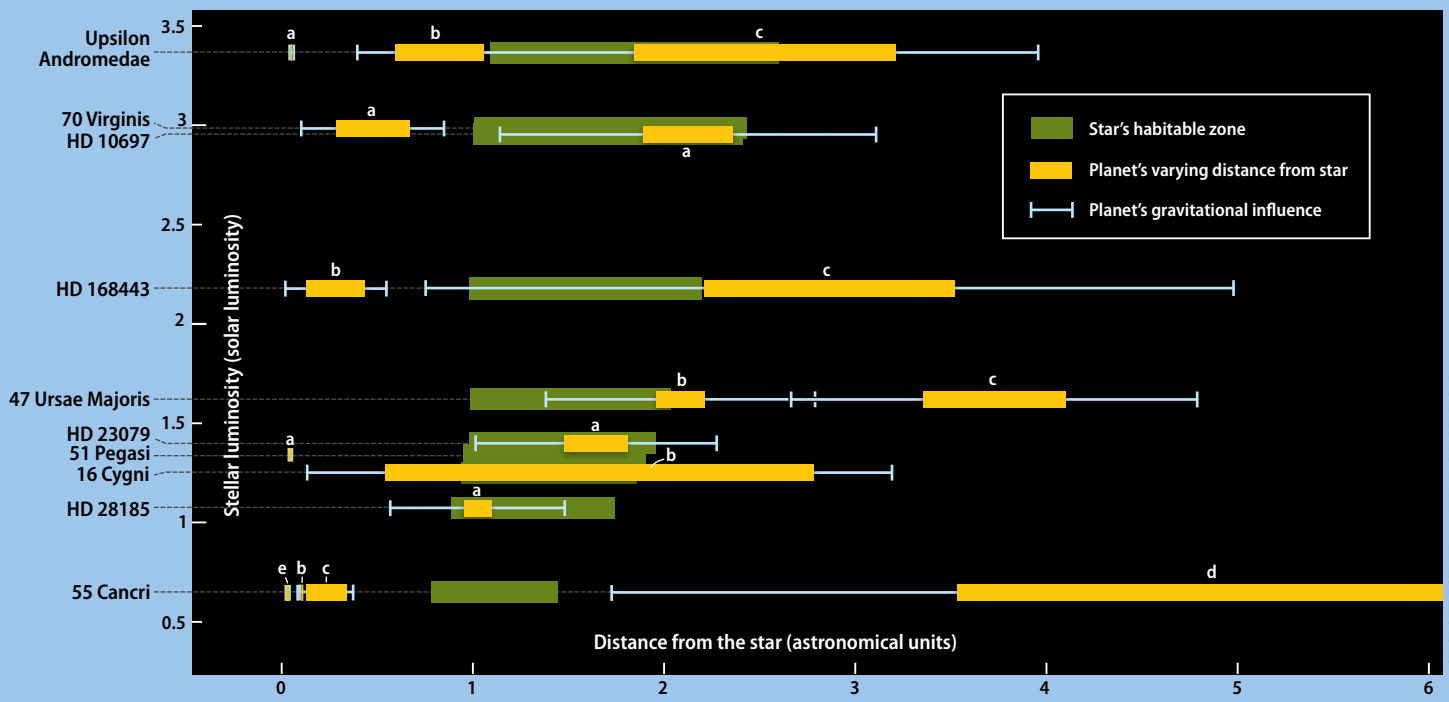
The first requirement — habitability over billions of years — puts strict constraints on several stellar parameters that are easily

hiding?

Location holds the key to finding extraterrestrial life.

/// BY MARGARET TURNBULL

Adequate distances for life



THE HABITABLE ZONES of 10 of the 160-plus known exoplanet systems are shown here. Some giant planets' gravitational pulls ruin the chances for terrestrial planets to occupy a star's habitable zone. Others give rise to the possibility of habitable moons. Those giant planets whose distances remain within the habitable zone could harbor habitable moons. HD 28185a and HD 23079a are two such planets.

observed. Young stars are not the best places to look. Not only has life had less time to develop, but, for the first billion years or so, asteroids and comets bombard the system, frustrating life's efforts to survive. It turns out that stars — like adolescents entering adulthood — go through a significant decrease in flaring and other chromospheric activity after an age of 3 billion years. The Sun is one such example of a star that significantly decreased its flaring activity at an age of 3 billion years. Whether this newfound calm helps life form is unclear, but, at the very least, this lets us identify and rule out the youngest stars from our searches.

Long-term habitability also points us to a limited range of stellar masses. A Sun-like star has a stable hydrogen-burning lifetime of about 10 billion years — plenty of time for civilizations to evolve. Solar-type stars are also bright enough that the width of their habitable zones can accommodate two or more planets' orbits.

Margaret Turnbull *is an astronomer at the Carnegie Institution of Washington. When she's not studying the stars, she bikes around the Washington area.*

Beware extremes

As many as 90 percent of the stars in our galaxy are small, dim objects called type-M dwarf stars — with masses at most half of the Sun's. Given their large numbers, we would like these M stars to host habitable planets. Because of their low masses, M stars have incredibly long lives — and, thus, long periods of near-constant luminosity. Around M dwarfs, life would have hundreds of billions, even trillions, of years to develop.

However, M stars have long been suspect in terms of their suitability for biology. Not only are their habitable zones narrow (about ⅒ the width of the Sun's), but these habitable zones are so close to the stars (¼ Mercury's orbit, or ⅒ Earth's orbit) that any planets orbiting there would certainly be tidally locked. This means one side of a planet always faces its star. So, instead of getting an even roasting, one side of the planet would be a blazing noonday Sahara, while the other is a freezing midnight Siberia.

Initially, scientists thought such a situation would be unstable,

THE ALLEN TELESCOPE ARRAY (ATA) will search 24 hours a day for radio signals from our Sun's stellar neighbors. If intelligent life exists, we assume it uses modes of communication similar to ours, and the ATA may detect a message. The ATA is a joint project between SETI and University of California, Berkeley. When complete, the array will comprise 350 twenty-feet-diameter (6.1 meters) dishes. ATA/RICK FORESTER

A ROCKY PLANET orbiting the narrow habitable zone around an M-type star would likely be tidally locked. The side facing the star would be searing hot, and the opposite side would be freezing cold. A temperate band could lie between the two extremes and harbor life. LYNETTE COOK

and moisture in the planet's atmosphere would condense into a giant icecap on the night side. This in itself would be bad for life, but what is potentially worse is M stars are famous for flares. All stars flare occasionally, including the Sun. But M-star flares can temporarily increase the star's luminosity by a factor of 100 or more, blasting out high-energy radiation and fast-moving particles that would dismember any nearby DNA molecules. Combine these outbursts with the habitable zone's close distance, and we're talking about putting a planet in an ultraviolet sterilizer.

Even with M dwarfs' close orbits and solar flares, all is not lost for these stars. If a tidally locked planet is massive enough to hold a substantial greenhouse atmosphere, one not much thicker than Earth's, atmospheric circulation could keep conditions fairly mild all around the planet. Add a little oxygen, which builds up when water molecules dissociate, and all the worst flares could do is drive ozone creation in the planet's stratosphere. Ozone, in turn, shields the surface from the harsh radiation of solar flares. Moreover, not all M-class stars flare radically. While M stars are perhaps not the best real estate in the galaxy, most scientists believe planets around M stars can possibly support life. The SETI (Search for Extraterrestrial Intelligence) Institute's target list contains many M stars that change brightness by less than 3 percent.

When it comes to stars that are just a few times the Sun's mass, however, the picture is bleak. These stars burn so brightly they use all of their hydrogen fuel before the planets around them even finish forming (see "Live fast, die young," April 2006). These stars swell into giants and fuse helium, carbon, nitrogen, oxygen, and other elements, synthesizing heavier elements all the way up to iron. That's as heavy as elements in normal stars can go. Then these stars die in explosions that create the rest of the natural elements and seed the galaxy with them.

Impressive? Yes. Good for life? No — or rather, not good for life today. We must never forget the first batches of massive stars created iron, nickel, carbon, oxygen, and the other building blocks of planets and life. These massive stars play a crucial role in the circle of life.

How many stars do *you* orbit?

After stars pass the mass, age, and flare-activity tests, we're sure they can provide roughly static habitable zones for long periods of time. But we still have our second criterion to consider: that nothing prevents planets from orbiting in those static habitable zones.

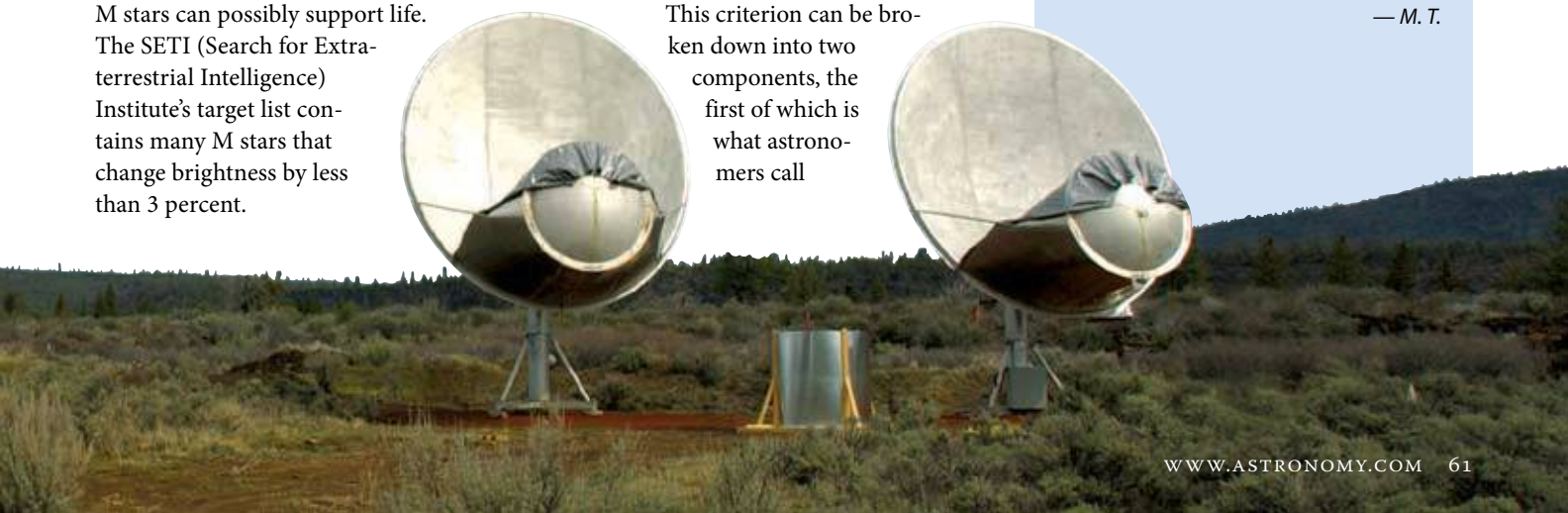
This criterion can be broken down into two components, the first of which is what astronomers call

POSSIBLE NOOKS FOR LIFE

The following places might harbor worlds that could possibly have water — the most important ingredient for life as we know it.

- **Terrestrial planets in a star's habitable zone**
  The "Goldilocks" zone, not too hot or too cold, around a star could have earthlike planets with temperatures that allow liquid water on the planets' surfaces.
- **Terrestrial moons in a star's habitable zone**
  Giant planets orbiting within a star's habitable zone could have big moons (like Saturn's Titan) with large amounts of liquid water.
- **Tidal habitable zones around giant planets**
  Giant planets in the cold outer regions of a planetary system could have moons that are continually tidally stretched (like Jupiter's Europa) as they orbit their massive parents. This generates heat, which could provide for liquid water.
- **Free-floating terrestrial planets warmed by internal radiation**
  As planets form, some are undoubtedly ejected into interstellar space. The galaxy could be full of these free-floating planets whose interiors, heated by decay of radioactive elements, stay warm enough for liquid water to exist for billions of years.
- **Floating oceans within giant planets**
  Some giant planets could have layers in their interiors where the temperature and pressure are just right for liquid water.

— M. T.



TOP 10 PLACES TO LOOK FOR LIFE

Jill Tarter, director of the SETI (Search for Extraterrestrial Intelligence) Institute's research center, asked me to list the highest-priority targets for the upcoming Allen Telescope Array (ATA). At the time, I questioned astronomy's connection to biology. But as I became further involved in this project, the connection became ever more apparent.

My target list for SETI eventually evolved into a catalog of stars that may harbor habitable planets like our own. These stars are our best bets for finding earthlike planets using both radio telescopes (like the ATA) and NASA's Terrestrial Planet Finder (TPF) mission (now facing budget cuts).

Stellar targets for SETI signal searches:

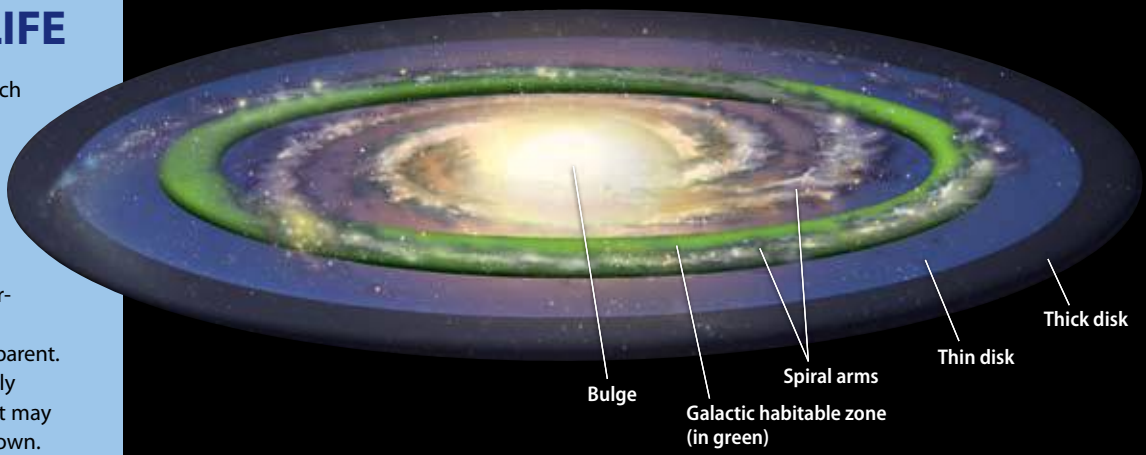
1. **Beta Canum Venaticorum:** Yellow G-type star, slightly larger than the Sun; 26 light-years away; has a possible distant companion.
2. **HD 10307:** Yellow G-type star, slightly hotter than the Sun; 41 light-years away; has a companion.
3. **HD 211415:** Yellow G-type star, slightly cooler than the Sun; 44 light-years away; in a binary system.
4. **18 Scorpii:** Yellow G-type star, slightly hotter and brighter than the Sun; 46 light-years away.
5. **51 Pegasi:** Yellow G-type star, slightly larger than the Sun; 50 light-years away.

Stellar targets for TPF searches:

1. **Epsilon Indi A**: Orange-red K-type star, about 75 percent the size of the Sun; 12 light-years away.
2. **Epsilon Eridani:** Orange-red K-type star, about 85 percent the size of the Sun; 10.5 light-years away.
3. **Omicron² Eridani:** Orange K-type star, about 90 percent of the Sun's size; 16 light-years away; in a triple system.
4. **Alpha Centauri B:** Orange-red K-type star, about 90 percent the Sun's size; a member of the closest star system to Earth, about 4.3 light-years away.
5. **Tau Ceti:** Orange-yellow G-type star, about 80 percent the Sun's size; 12 light-years away.

— M. T.

The galaxy's most suitable neighborhood



THE SUN orbits in the Milky Way's habitable zone. Planetary systems too close to the galactic center would interact frequently with each other. The number of stars and the stars' metallicities are lower at greater distances from the galactic center. In between, the density and metal content of stars are more suitable for planets that could have life.

multiplicity. The Sun is a single star, which is slightly unusual: About two-thirds of otherwise Sun-like stars come in multiples. I don't mean to suggest that two, or more, stellar parents is necessarily a bad thing, but understanding the stars' orbits is crucial. For example, a second star could:

- orbit so close to its primary that the habitable zone encircles both stars — any earthlike planets will simply enjoy two sunsets per day;
- sweep through or come very close to the habitable zone, gravitationally perturbing the orbits of any planets there and possibly ejecting the planets altogether;
- orbit far enough away that it does not perturb the habitable zone but introduces a randomly changing luminosity that would interfere with the climate of any planets;
- have such a large orbit that any planets in the habitable zone are completely unaffected.

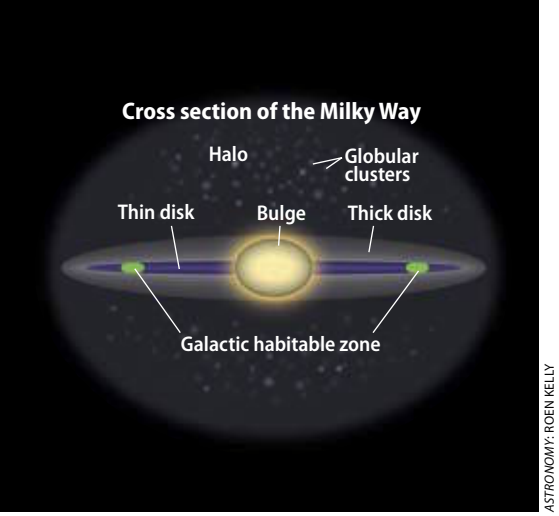
In the fourth case, both stars have "safe" habitable zones, which makes these systems doubly intriguing. Only small ranges of separation between the stars cause problems.

Most binaries appear safe, falling either into the first or fourth scenario. Triple and quadruple star systems sound more exotic, but they are just as likely as binaries to be safe harbors for life. Multiple systems are hierarchically configured: A triple almost always consists of a close double orbited by a distant third; a quadruple consists of two pairs; a quintuple of two pairs plus a distant third around one of them; and so on.

A star's stuff is important

Thanks to the diligent efforts of planet hunters, we know about some 200 planets orbiting more than 160 of the Sun's stellar neighbors. Each of these planetary systems has to be assessed for stability, and a fair number can be ruled out because the giant planet interferes with the habitable zone (see "Adequate distances for life," page 60). Most of the giant planets are on elliptical orbits and have gravitational influences that extend beyond their own orbits. Where such a gravitational influence extends into a star's habitable zone, it is unlikely any earthlike planets could maintain stable orbits. There are several interesting cases, however, (like Mu [μ] Arae) where giant planets orbit within the habitable zone. If these giants have big moons, similar to Jupiter's and Saturn's satellites, the moons could be adequate hosts for life.

The star's composition is the second factor that could prevent planets from orbiting in the habitable zone. We know stars and their planets form at the same time out of the same material. As density waves sweep through the galaxy, they compress gigantic clouds of gas and dust. Cloud fragments then collapse gravitationally into stars and planetary systems. But not all clouds are the same; some are deficient or enriched in elements heavier than helium, (astronomers call these elements metals) depending on the local history of massive-star explosions. Thus, some stars are metal-poor, and some stars are metal-rich compared to the Sun.



ASTRONOMY: ROEN KELLY

HOW TO BE A GOOD PARENT STAR

DO remain at approximately the same luminosity for billions of years.
DO form out of a cloud with enough metal content to build up terrestrial planets.
DO stay in between galactic spiral arms for as long as possible.
DO NOT emit gigantic flares that singe the surfaces of nearby planets.
DO NOT form with companion stars that swoop in and out of your habitable zone.

— M. T.

This is important because astronomers have found metal-rich stars are more likely to have close-orbiting giant planets. Astronomers don't yet know how a star's metallicity correlates to the presence or absence of terrestrial planets, but it makes sense that iron-bearing planets like ours wouldn't form out of clouds that had no iron to begin with.

On the other hand, high-metallicity stars have close-orbiting giant planets because after the stars formed, there was still lots of material orbiting the new stars. That material aggregated into giant planets.

Location, location, location

Finally, we need to question the habitability of the Milky Way Galaxy itself. Are all of the Milky Way's neighborhoods equally good for life? Not likely. Our Sun inhabits the galactic backwoods, where stars are separated, on average, by a few light-years and rarely pass within a comet's throw of one another. Stars in more crowded areas, such as the central galactic bulge, globular clusters, and spiral arms, are more likely to have close approaches from stellar neighbors. Such visits could destabilize planetary systems in the process.

The Sun probably formed in a loosely associated cluster of newborn stars. It may be that a few of our minor planets beyond Pluto (like Sedna) originally belonged to another star. But the Sun is a rural star now, and it will likely remain so for a long time. Although scientists don't fully understand the Sun's orbit around the galactic center, it seems the Sun orbits at a special location in the galactic disk called the co-rotation zone. This is where the galaxy's spiral pattern and the stars between arms move at roughly the same speed.

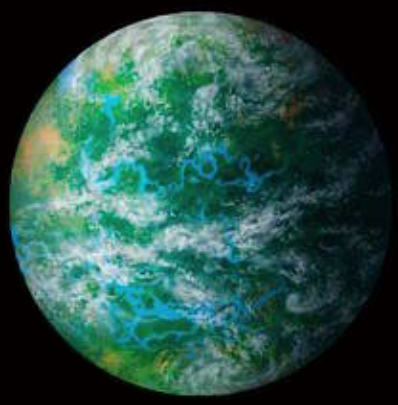
Closer to the galactic center, solitary stars move faster than the spiral pattern and, therefore, continually pass through the spiral arms. Spiral-arm regions of massive-star formation and high-energy radiation could fry life-forms. And regions of interstellar gas and dust could interfere with a planet's climate by seeding the formation of rain clouds. By sticking to the middle lane, the Sun can remain suspended between spiral arms for billions of years.

Biology is a cosmic balancing act, with the best homes nestled in special nooks around special stars. These stars orbit special parts of the galaxy. Does it go beyond that to special pockets of galactic clusters throughout the universe?

If there is one thing life on Earth suggests, it's that there is an exception to every rule. Scientists have found life in the most unexpected places on our planet, which is promising for those searching for life outside of our solar system. And now that we have a better idea of where to look — from a star's composition to its age to its orbit — we are that much closer to finding out if we're not alone.

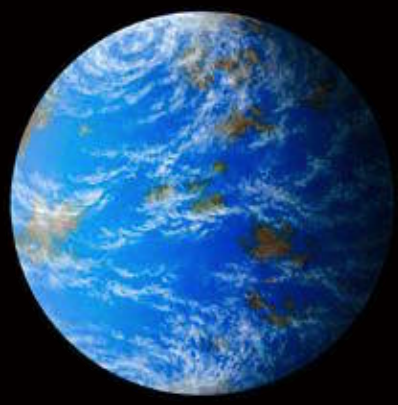
The four basic types of terrestrial planets

A desert world, devoid of water; inside the habitable zone



A hot, humid jungle world with a rich carbon dioxide atmosphere; at the inner edge of the habitable zone

A frozen, ice-covered world; just outside the habitable zone



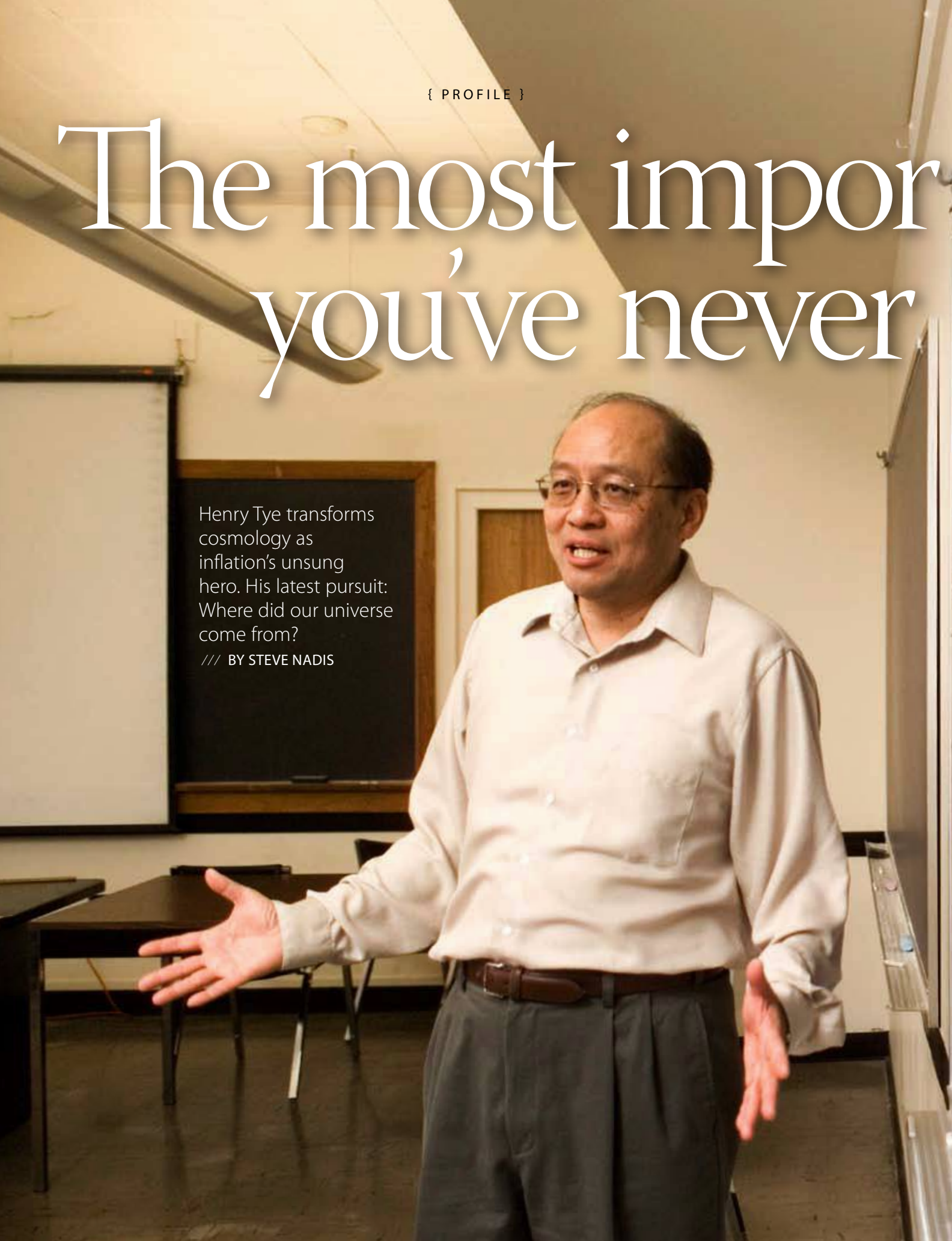
A water world covered by oceans and landmasses; in the middle of the habitable zone

A PLANET'S LOCATION makes all the difference. Here are four possible temperatures: too scorched, too humid, too cold, and just right. The best location, and therefore temperature, for an earthlike world is in the habitable zone's center. LYNETTE COOK

The most impor you've never

Henry Tye transforms cosmology as inflation's unsung hero. His latest pursuit: Where did our universe come from?

/// BY STEVE NADIS



tant cosmologist heard of

"My entrée to the field of inflation was magnetic monopoles. That and Henry Tye," Massachusetts Institute of Technology (MIT) physicist Alan Guth recalls. Tye, a physicist based at Cornell since 1978 — as a postdoc, then faculty member — introduced Guth to cosmology in the late 1970s. The two postdocs worked together closely, right up to the moment in December 1979, when Guth — toiling on his own in the middle of the night — hit upon the notion of cosmic "inflation," an explosive growth spurt in the infant universe.

Inflation is now a central tenet of cosmology, and Guth became famous for his discovery, but he acknowledges his debt to Tye: "Henry contributed enormously. If it weren't for him, I never would have been in a position to come up with an idea like inflation." Yet Tye has not received much recognition for his contributions to that momentous idea.

If Tye did nothing more than lay the groundwork for Guth's grand leap — guiding Guth to the top of the precipice, pointing him in the right direction, and then giving him a judicious shove in the form of a crucial hint — that alone would be a significant accomplishment.

But Tye has played far more than a supporting role, moving on from that early collaboration to explain inflation through string theory. In addition, he's shown how observations of cosmic strings — extraordinarily long, dense, thin filaments produced at inflation's end — would not only affirm inflationary cosmology but also offer experimental validation to string theory itself, something that has been lacking for decades.

Lately, Tye has developed new strategies for probing the universe's origins. "If you look at his whole career, Henry really is an unsung hero," says Joseph Polchinski, a physicist at the University of California, Santa Barbara.

"He's laid the groundwork for addressing important cosmological questions through string theory."

HENRY TYE may have missed his 15 minutes of fame when he took a 6-week trip in 1979 while Alan Guth wrote his famous inflationary universe paper. But Tye's quietly established himself as an integral contributor to cosmology's evolution during his 30-year-plus career. JASON KOSKI, CORNELL UNIVERSITY PHOTOGRAPHY

IN 1974, Tye earned his Ph.D. from the Massachusetts Institute of Technology. His wife, Bik, also received her Ph.D. from MIT the same year. COURTESY HENRY TYE

Henry Tye's early years

Born in Shanghai in 1947 and raised in Hong Kong, Tye came to the United States in 1967 to study physics at the California Institute of Technology (Caltech). He went to MIT for graduate studies, earning his Ph.D. in 1974. After postdoctoral stints at the Stanford Linear Accelerator Center and Fermilab in Chicago, he landed at Cornell, where he crossed paths with Guth — someone he'd known vaguely from MIT.

During lunch one day, they discussed magnetic monopoles — peculiar, hypothetical particles with an isolated (north or south) pole. After much prodding, Guth agreed to team up with Tye to determine the number of monopoles produced in the Big Bang. They came up with a large number, totally at odds with standard cosmology, because no monopoles have ever been detected. What could be suppressing monopole production, Tye and Guth wondered.

The answer they hit upon was "supercooling." When water is supercooled, for example, its phase transition from liquid to solid occurs well below the normal freezing point. Likewise, the phase transition in the early universe thought to give rise to monopoles could be delayed by supercooling so that it occurred at a lower temperature, with far fewer monopoles produced. This was a significant result, and they rushed to finish their paper before Tye left in late December 1979 on a 6-week trip to China.

While revising the paper, Tye suggested to Guth that supercooling might affect the universe's expansion, even though Tye hadn't done the calculation himself. Guth explored this possibility on the night of December 6 and through the following morning. He then discovered that supercooling would have a

WHILE STROLLING around Cornell University's Beebe Lake in 1998, Henry Tye and New York University physicist Gia Dvali discussed how inflation works. Their walk led to a paper that solved a long-standing problem for inflationary theory. JASON KOSKI, CORNELL UNIVERSITY PHOTOGRAPHY

HENRY TYE, middle, comes from a family of seven. In 1967, he left Hong Kong to study physics at the California Institute of Technology. COURTESY HENRY TYE

EVEN AT HOME, Tye could be found working on the monopole problem that eventually led Alan Guth to the inflationary universe. COURTESY HENRY TYE

TYE VISITED with his grandmother during his "memorable" trip to China in 1979. COURTESY HENRY TYE

tremendous effect on cosmic expansion, sending the universe into a period of runaway growth.

Later that morning, he contacted Tye and asked whether they should mention this accelerated-growth phase in their paper. Tye hesitated because it sounded like they were invoking the cosmological constant to explain away monopoles, thereby solving one problem with an even bigger problem no one understood. With his trip imminent, Tye felt they didn't have time to address such a big new topic adequately in a paper that was virtually complete and already too long.

Before Tye left town, Guth asked if he could pursue a paper on the exponential-growth idea on his own. Given the competition they faced in this area, Guth felt like 6 weeks was a long time to wait. Tye agreed and encouraged him to press onward. Guth wrote his landmark paper, and the rest is history.

The trip to China was "memorable," Tye says, apart from the establishment of the inflationary-universe theory that overturned cosmology while he was gone. "For one thing, I hadn't seen my grandmother in a long time," he recalls.

But the main reason for his travels was a conference in Guangzhou, marking the first time since Mao Zedong's (1893–1976) rule that physicists who had left China were allowed back into the country. "That was a big deal," Tye recalls. "Things were finally opening up in China."

Yet the ill-timed journey exacted a steep cost on his career. "Had he not gone to China, Henry surely would have been a coauthor on the first inflation paper," Guth says.

Steve Nadis, *a frequent contributor to* Astronomy, *often writes about both the brains and branes of cosmology.*

But Tye has no hard feelings toward Guth. "Alan saw how exponential growth could solve many of the cosmological problems we faced, and he deserves the credit."

Nevertheless, Tye says he "missed the boat and would have to wait for the next big boat." He was holding out for a big idea, as he didn't see the point of writing a small paper on inflation when hundreds of papers on the subject were being churned out. He turned to string theory in the hopes it could provide a more thorough understanding of inflation.

COURTESY HENRY TYE

TYE TRAVELED to China in 1979 to attend a conference in Guangzhou, where he met Deng Xiaoping (1904–1997). This conference marked the first time since Mao Zedong's (1893–1976) rule that physicists who'd left China were allowed back in the country.

Of branes and strings

Tye initially thought it would take him just a year to devise a string-based model of inflation. "But after 2 years went by, and then 5, I sort of lost hope," he says. The problem, he explains, is that "string theory, as formulated in the 1980s and most of the 1990s, did not show where inflation could possibly come from."

A breakthrough occurred in the mid-to-late 1990s with the advent of so-called braneworld cosmology — a term coined by Tye and a student. In 1995, Polchinski showed that in addition to 1-dimensional strings, there are other fundamental, higher-dimensional objects in string theory called membranes, or "branes." According to the braneworld view, our universe exists on one brane, and we could be unaware of other universes sitting on other branes in hidden dimensions.

A 1998 paper by Nima Arkani-Hamed (now at Harvard University), Savas Dimopolous of Stanford, and Gia Dvali of New York University showed that the extra dimensions of string theory could be large — on the order of a millimeter — which allows for branes to move in space. Tye immediately began contemplating new possibilities.

Dvali gave a talk at Cornell in the fall of 1998, and, afterwards, he and Tye took a long stroll through campus, circling picturesque Beebe Lake. "It was beautiful, but we weren't looking at the scenery," Tye says. Instead, he and Dvali were trying to figure out how inflation works.

During their walk, they devised a geometric picture of the process: Inflation occurs as two parallel branes slowly come together under the tug of gravity until they eventually collide and melt, releasing the energy of the hot Big Bang.

"Brane inflation," as Dvali and Tye called it in their 1999 paper, offers an answer to the question that had plagued inflationary theory for 20 years: Where does the potential energy, or "vacuum energy," that drives inflation come from? Dvali and Tye say it's simply the gravitational potential energy of two branes (or two stacks of branes) separated from each other in higher dimensions. The strength of that gravitational potential depends on the distance between the branes. This explanation provides exactly what is needed for inflation: A form of vacuum energy that remains almost constant at first, slowly diminishes as the branes approach, and ultimately is converted into matter and radiation. "Getting this to happen in string theory had been a formidable challenge," says Polchinski. "What Dvali and Tye did was fantastic."

Many of Tye's peers agree. "Brane inflation has been very influential," claims Clifford Burgess of the Canadian-based McMaster University and Perimeter Institute. A raft of string inflation models has come out since 1999, adds Burgess, "and, with just one exception, all those models rely on the relative motion of branes to drive inflation."

> "TYE WAITED UNTIL all the ingredients were there to produce what still seems to be a great idea."
> — *Joseph Polchinski*

The result was gratifying for Tye, who'd taken 20 years to do something he initially figured to knock off in 1. "But 20 years is still better than never," he says.

Polchinski is impressed that Tye took his time before writing his first paper on inflation. "He didn't settle for some half-baked idea. Instead, he waited until all the ingredients were there to produce what still seems to be a great idea." Furthermore, Polchinski notes, Tye did not sit around for 20 years doing nothing, but instead made fundamental contributions to string theory, developing some of the "ingredients" necessary for formulating ideas in string cosmology like brane inflation.

Still much to learn

In 2002, following up on his work with Dvali, Tye had a key insight: The collision marking the end of brane inflation leads to a phase transition that produces cosmic strings but no other defects. His calculations ruled out the creation of magnetic monopoles — the point-like defects he and Guth originally sought to suppress — and domain walls — sheet-like defects that would quickly dominate the

COSMOLOGY 101

COSMOLOGICAL CONSTANT
The energy density of the vacuum, which may cause space's expansion to speed up. Einstein introduced — then withdrew — the concept.

INFLATION
A period of extremely rapid expansion, during which the observable universe expanded by a million trillion trillion times in less than a trillionth of a second.

STRING THEORY
A physical theory that views subatomic particles as loops of energy. Strings have length but no dimension.

BRANE
A fundamental, multidimensional object in string theory. If our entire universe sits on a brane, we could be unaware of other universes on other branes in hidden dimensions.

MONOPOLE
A hypothetical particle with a single magnetic pole (north or south) instead of the usual two; thought to have formed in the Big Bang.

COSMIC MICROWAVE BACKGROUND
The imprint of radiation's separation from matter; records the beginnings of large-scale cosmic structure.

WHERE DID our universe come from, wonders Tye. He's seeking the answer to this question through physics rather than rhetoric. JASON KOSKI, CORNELL UNIVERSITY PHOTOGRAPHY

TYE CONTINUES to shape the field. Here, he celebrates his 50th birthday with students and staff at Cornell. COURTESY HENRY TYE

universe and create a picture totally at odds with astronomical observations.

In the simplest scenario, Tye says, a brane and "antibrane" would crash and annihilate each other, heating up the universe in the process. (A brane has the same density as its antibrane but an opposite "charge." Unlike an electric charge, this charge is carried by a string force.) The cosmic strings emerging from this wreckage should survive and be detectable today, Tye predicts.

Polchinski, among others, applauds the achievement. "You used to be washed up in physics by the time you hit 30," he says. But some of Tye's most groundbreaking work, like brane inflation and cosmic-string production, occurred well into his 50s, which is spectacular to see, Polchinski adds. "Rather than sitting back and trying to keep abreast of the literature, he's still helping to shape the field."

Tye is not done "shaping." He's interested, among other things, in how astronomers might find cosmic strings. For example, he predicted a range of "tensions," or energy densities, these strings should possess and the likely observational consequences. If cosmic strings are as heavy as once postulated in the 1980s, they would have left a dramatic imprint in the cosmic microwave background (CMB) that would contradict all empirical data. Values of string tension predicted by Tye, in the aftermath of brane inflation, are still within allowable limits. He estimates that up to 10 percent of the temperature fluctuations, or anisotropies, in the CMB could be attributed to cosmic strings.

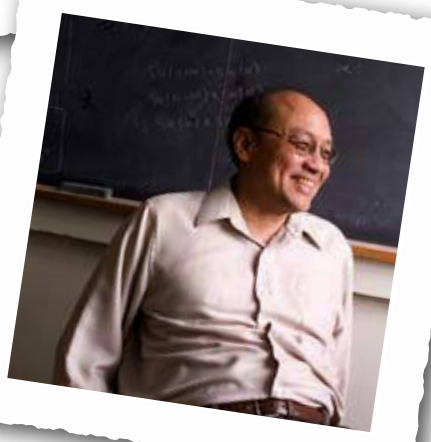
Instead of mapping individual points in the CMB sky, Tye suggests looking for adjacent regions that have slightly different temperatures. A fast-moving cosmic string (they're expected to fly through space at almost light-speed) would push CMB photons on the front side, making them appear "warmer" than photons on the back side. Researchers are now looking for this signature in WMAP data, and it should be even easier to detect when data come in from the Planck Telescope scheduled for launch later this decade.

Tye's major goal, of course, is to see a cosmic string. Then, scientists will try to measure the tension by gauging the string's gravitational influence. String theory predicts that cosmic strings should have a range of tensions. The tension tells us the energy scale that prevailed during inflation. That's because a cosmic string's energy density is trapped forever at the inflationary energy scale.

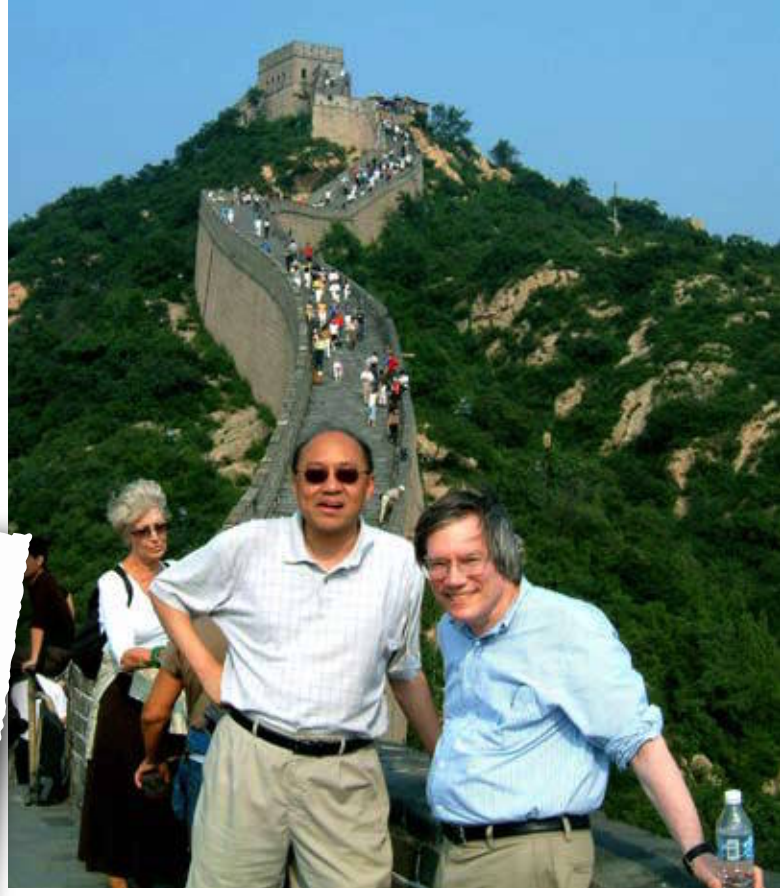
If string theory is right, says Tye, three cosmic strings should come together to form a junction. Spotting something like that in the sky would be a spectacular confirmation of both brane inflation and string theory as a whole.

Tye considers brane inflation "a simple model that seems to be generic," and he hopes it is ultimately born out. Yet he's even more excited about the prospect of providing experimental support for string theory, which is supposed to be a theory of the universe — of which brane inflation is just a part.

IN 1998, Tye walked around Beebe Lake with Gia Dvali (not shown) and came up with the idea of brane inflation. In 2004, during winter break, he enjoyed a walk with his family around the same lake — no word yet on what they came up with. COURTESY HENRY TYE



TYE'S NEXT PURSUIT: using cosmic strings to find out where our universe came from. Tye's 4-decade-long career provides him with perspective and courage for taking on such bold pursuits. JASON KOSKI, CORNELL UNIVERSITY PHOTOGRAPHY



WHILE ATTENDING a symposium on particle astrophysics and cosmology in August 2005 in China, Tye and Alan Guth spent some time touring the Great Wall. COURTESY HENRY TYE

"So much effort has been put into string theory, yet some people say it's not physics, because after 20 years, we still can't make a testable prediction," Tye notes. "That's why I can't think of anything more important than determining the tension of cosmic strings."

From nothing, something

Well, perhaps that's not quite true. Tye has already turned his attention to another question that might be considered even more important: Where did our universe come from?

Perhaps, says Tye, the universe originated from nothing — no matter, energy, space, or time — by means of a "quantum fluctuation" in the same way particles pop in and out of existence, according to quantum mechanics. Ideas of spontaneous creation like this have been proposed since the 1980s — by Alexander Vilenkin of Tufts University, Stephen Hawking of Cambridge University, and others. But Tye believes the problem is best approached through string theory, where both space and time are derived quantities, rather than eternal features of nature.

String theorists now believe between 10,100 and 101,000 possible universes exist. If you start with nothing, Tye asks, which universe is preferred? Our universe should begin with a state that has the maximum probability, he argues. And his preliminary calculations suggest a 4-dimensional inflationary universe similar to our own is, indeed, most likely.

> "I CAN'T THINK of anything more important than determining the tension of cosmic strings." — *Henry Tye*

Tye hopes to find a way around the anthropic principle — an idea, simply stated, that we live in a universe with properties (such as constants of nature and physical laws) set the way they are because, otherwise, intelligent life-forms would not be around to ponder such questions. Many scientists find that line of reasoning unpersuasive, given that some forms of the anthropic principle are guaranteed to be true. Tye prefers to seek answers to our universe's mysterious origins from fundamental physics and first principles, rather than from rhetorical arguments.

Nevertheless, telling the physics community where inflation comes from and how the universe could arise from nothing takes some chutzpah — it's a high-risk endeavor Tye would have steered clear of earlier in his career. But he now realizes sometimes you have to be bold.

More than a quarter century ago, when he shied away from inflation out of fear of getting dragged down by the cosmological constant, Tye learned a painful lesson: Timidity has a price. He used to worry about making a mistake. He's since learned that "If I get something wrong, I'll still live. It's okay for a theorist to be wrong every now and then, so long as you occasionally come up with a good idea."

By all accounts, Tye has had more than his share of the latter, offering potential solutions to some of the biggest quagmires of the day. Although he "missed the boat" back in 1979, the vessels he's caught since may carry us to the next level of understanding.

ASK ASTRO

Astronomy's editors and experts from around the globe answer your questions about the cosmos. This month: the space between planets, what the "flat" universe means, and determining stellar ages.

NUMBER GAME

Q: Is it a coincidence that most of the planets fall within the Titius-Bode law's boundaries?

— **JOHN RICCIARELLI,** MALDEN, MASSACHUSETTS

A: In 1766, Johann Daniel Titius of Wittenberg discovered a numerical progression that roughly matched the orbital distances of the known planets — Mercury through Saturn. In 1772, Johann Elert Bode of Berlin published the progression. When William Herschel discovered Uranus in 1781, the planet fit in the number series. This addition provided further evidence for the Titius-Bode law, which was widely accepted in the astronomical community until Neptune's discovery in 1846. Neptune broke the "law." **So, yes, it's just a coincidence that most of the planets fall within the Titius-Bode law distances.**

Titius discovered the relation after playing with number sequences and finding one that worked. Yet, scientists have long sought deeper explanations for the Titius-Bode progression. In fact, so many ideas have been advanced that *Icarus*, a leading journal of planetary science, no longer accepts papers that allege to explain the series.

In our solar system, the major planets' spacing is likely an outcome of the chaotic processes involved in forming planets through the collisional accumulation of progressively larger orbiting bodies. Also, our planets seem to have stayed close to the orbits in which they formed. The gas and dust disk that produced our solar system had a relatively short life span, which didn't allow enough time for planets to migrate elsewhere. This is different from many of the extrasolar planetary systems known.

The progression also doesn't apply to extrasolar planetary systems, discovered in the past decade. Scientists suspect gravitational interactions between forming planets and the dusty disk explain how some gas-giant planets become "hot Jupiters," orbiting a star well inside the distance of Mercury's orbit. This observed planetary migration limits the applicability of simple numerical progressions to extrasolar systems. — **ALAN BOSS,** CARNEGIE INSTITUTION OF WASHINGTON

The sequence Titius and Bode came up with is based on the following equation:

$$a = \frac{(n + 4)}{10}$$

where n = 0, 3, 6, 12, 24, 48, 96, 192, 384 (each number, except for 3, is double the preceding number)

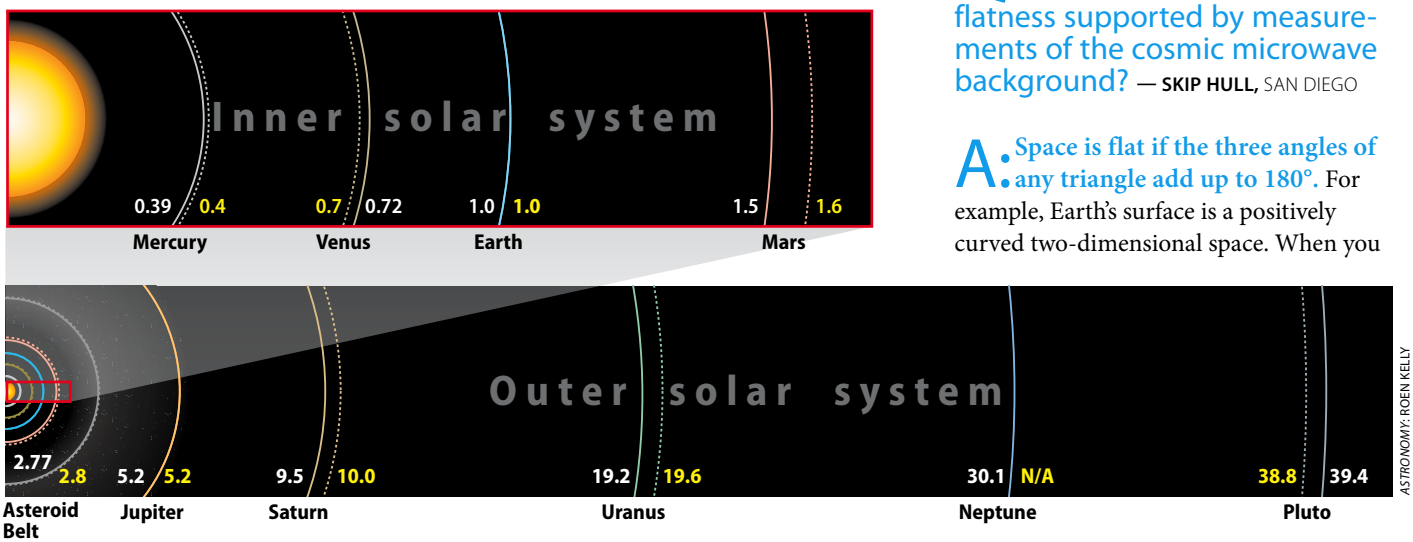
a is the average distance measured in astronomical units (1 AU is the Earth-Sun distance)

FLAT UNIVERSE

Q: What is meant by the term "flat universe"? How is this flatness supported by measurements of the cosmic microwave background? — **SKIP HULL,** SAN DIEGO

A: Space is flat if the three angles of any triangle add up to 180°. For example, Earth's surface is a positively curved two-dimensional space. When you

Estimate meets observation



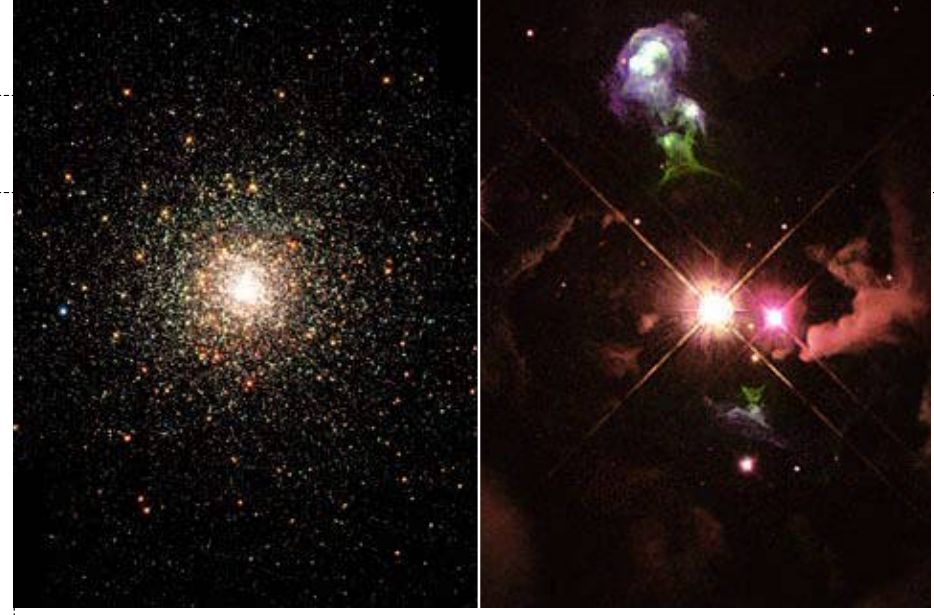
ASTRONOMY: ROEN KELLY

ODDLY ENOUGH, each planet in our solar system (except for Neptune) is at a distance the Titius-Bode law estimates. This numerical relation is just a coincidence, because it does not apply to other planetary systems. In this illustration, numbers in white are the planets' (and asteroid belt's) actual average distances; numbers in yellow are the distances determined from the Titius-Bode law.

go from the North Pole to Ecuador to Congo and back to the North Pole, you make a triangle whose angles add up to about 270°. All other triangles on this spherical surface also give more than 180°. A saddle-shape surface is negatively curved. Draw a triangle on it, and the angles will sum to less than 180°.

Cosmic microwave background (CMB) researchers using data from the Wilkinson Microwave Anisotropy Probe (WMAP) have measured the angles of the longest triangle you can imagine. One corner is on Earth, and the other two are so far away that light has traveled about 13.3 billion years to reach us. Scientists found the angles of this triangle add up to 180°, to within small measurement uncertainties.

The far edge of this distant triangle corresponds to the size of a typical spot on the CMB map — each splotch has an angular size similar to the Moon's. The spots are hot and cold areas in the hydrogen plasma that filled the infant universe, and have been imaged with sensitive microwave cameras aboard WMAP. — **MAX TEGMARK,** MASSACHUSETTS INSTITUTE OF TECHNOLOGY, CAMBRIDGE



NASA AND THE HUBBLE HERITAGE TEAM (AURA/STScI)

TWO WAYS astronomers determine stellar ages are by observing star clusters and by studying a newborn star. Globular cluster M80 (left) is filled with old stars; the cluster is roughly 13 billion years old. The object called Herbig Haro 32, on the other hand (right), has a central infant star — which is only a few hundred thousand years old. Many young stars spew jets that collide with interstellar material. This collision is shown here in false color, where green is hydrogen and blue is sulfur.

AGING STARS

Q: How do astronomers determine the ages of stars? — **OSCAR MICHELETTI,** BUENOS AIRES, ARGENTINA

A: As stars age, a variety of observational characteristics naturally change. Some are dramatically obvious, while others are subtle. **The calculated age's accuracy depends on the star's mass, its state of evolution, and whether or not it has a companion.**

Astronomers obtain the most precise age estimate when the star is in a cluster. Main sequence stars are supported by nuclear fusion in their cores. The higher the mass, the faster a star uses its fuel and the shorter its lifetime on the stable main sequence is. By combining theory and observation, we can derive the age of a cluster — and hence the ages of its stars, because they were all born at almost the same time — from the lowest-mass star that is still fusing hydrogen. Higher-mass stars would have already become dying giants and supergiants.

Some cluster stars may even be further along on the evolutionary track, setting into a long, slow decline as compact white dwarfs. The ages of the dimmest, hence oldest, white dwarfs give good results as well (although these objects are more difficult to observe).

When we plot a cluster's stars on a Hertzsprung-Russell diagram (luminosity versus temperature), we then "age" the cluster by computer analysis to try to replicate the observations. To computationally age a cluster, we must know the cluster's distance and metal content (which partially controls luminosity and temperature).

While single stars are more difficult to deal with, we can still derive ages (and masses) by locating each star on temperature and luminosity plots (HR diagrams). Because stable main sequence stars change slowly, the results are more approximate than those for stars still forming, or those in the later stages. Once the giant (or supergiant) stages commence, during which time a star changes quickly, ages are more precise.

We can identify newborn stars by observing their surrounding birthplaces. Infant stars emit powerful winds in opposing jets.

Astronomers also look at stellar rotation speeds. Stars rotate fastest when they're first born. Lower-mass stars, those with outer convection layers (in which the stellar gases rise, radiate and cool, and then fall), generate magnetic fields that are pulled outward by stellar winds. Because the field lines are still anchored at the star, they consequently brake the rotation. The older the star, the slower is its spin, with the rate of decline depending on stellar mass. Because stellar activity (starspots and related effects) depends on rotation speed, it too can give some idea of stellar age.

Convection also has a subtle effect on a star's chemical composition. Nuclear reactions at relatively low temperatures easily destroy lithium. As convection cycles the outer stellar gases up and down, the amount of lithium declines. Young stars have lots of it; older ones have very little.

While the various methods often give different results, combining them gives astronomers a reasonably good age. The most accurate result is reserved for our star. Radioactive dating (in which we compare the amounts of radioactive isotopes with their final daughter products) of the oldest rocks — meteorites — gives the solar system's age as 4.6 billion years. Because we have every reason to believe the Sun and planets formed together, the Sun must also be 4.6 billion years old. — **JIM KALER,** UNIVERSITY OF ILLINOIS, URBANA-CHAMPAIGN

Send your questions to: askastro@astronomy.com; or write to: Ask Astro, P. O. Box 1612, Waukesha, WI 53187. Be sure to tell us your full name and where you live. Unfortunately, we cannot answer all questions submitted.

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Put away your eyeglasses. Tele Vue's DioptRx lenses correct astigmatism. /// BY MIKE D. REYNOLDS

The sharpest image

At last! There's help for the observer

with astigmatism. For the first time, amateur astronomers suffering from this malady can cast off their eyeglasses and observe like the rest of us. Generally speaking, the ability to focus a telescope allows observers to correct for near-sightedness and farsightedness. But a focuser won't correct another common eye defect: astigmatism, where light rays focus at different points, creating a blurred image. Most people who suffer from this problem find it intrusive only at low magnifications; some see its effects at all magnifications.

In the past, some observers have had a special eyeglass prescription for astigmatism only. Others went to the expense of having corrector lenses produced for their telescope to correct for their astigmatism. Finding a better solution for this inconvenience was Tele Vue's goal.

DioptRx is a corrector-lens system that attaches to the top of specific Tele Vue long eye-relief eyepieces (see table below).

DIOPTRX-READY TELE VUE EYEPIECES

Nagler Type 4 — 12mm, 17mm, 22mm
Nagler Type 5 — 26mm, 31mm
Panoptic — 22mm, 27mm, 35mm, 41mm
Plössl — 32mm, 40mm, 55mm
Radian — 3mm, 4mm, 5mm, 6mm, 8mm, 10mm, 12mm, 14mm, 18mm

Because each person suffering from astigmatism has a different prescription (each eye also can be different), Tele Vue offers DioptRx corrector lenses in 0.25-diopter steps from 0.25 diopter up to 2.5 diopter, and also 3.0 and 3.5-diopter correctors.

If you examine your prescription, you'll note a "cylinder" value — plus or minus — for each eye. For example, my recent eye exam revealed cylinder values of +1.25 for my right eye and +0.25 for the left. Because my right eye is my observing eye, that's the DioptRx correction I want — 1.25 diopter. (Note: Use cylinder values only. Ignore all "spherical" and "axis" values as well as all plus and minus signs.)

I tested DioptRx lenses on myself and on several of my astronomy-lab college students. I was interested in seeing not only how DioptRx worked for an experienced observer, but also what difference a novice at the telescope would see.

For the test, I used various Tele Vue eyepieces and three different telescopes, including a 3.2-inch Vixen ED80sf apochromatic refractor, an 8-inch Meade LX200 GPS Schmidt-Cassegrain telescope, and a Coulter Odyssey 10-inch Newtonian reflector on a Dobsonian mount. I observed under dark skies and good conditions, viewing a variety of bright and faint objects at different magnifications.

THE 32MM Tele Vue Plössl eyepiece is one of 21 that come "DioptRx-ready" (see list at left). ALL PHOUTOS: *ASTRONOMY*: WILLIAM ZUBACK

T. A. RECTOR AND B. A. WOLPA/NOAO/AURA/NSF

WHAT IS ASTIGMATISM?

Astigmatism is a common condition of the eye in which the cornea curves unevenly. (Rather than being round, the cornea resembles a football.) The root of the word is Greek, meaning "without" ("a") "a point" ("stigma"). The result of astigmatism is out-of-focus vision along one axis. Diagnosing astigmatism requires a standard eye examination with a refraction test, which also determines if one is nearsighted or farsighted. Once diagnosed, correcting astigmatism requires glasses or hard contact lenses; soft contact lenses have not proved as effective. — *M. D. R.*

A DioptRx lens fits over the top of an eyepiece once you remove the original rubber eyeguard and install the DioptRx (and its eyeguard). Next, you must orient the corrector lens for your eye by rotating it. Tele Vue prints letters on the side of each DioptRx lens so you can return to a certain alignment. I found it simple enough to turn the correcting lens until the stars became sharp. DioptRx is easy to use, and when others not suffering from the same amount of astigmatism as you want to look through your telescope, it's easy to remove, too.

I was impressed with how much better images appeared through all three telescopes and eyepiece combinations with the DioptRx lens installed. For me, this worked especially well at low magnifications. (I don't have issues with astigmatism at higher magnifications.) Stars were sharp to the edge of the field of view in all eyepieces.

Mike D. Reynolds — *the Dean of Mathematics and Science at Florida Community College — wears glasses for nearsightedness and suffers from astigmatism.*

Because I teach college astronomy courses, I was interested in my students' reactions to DioptRx. In order to participate, I asked each student suffering from astigmatism to provide a recent eye prescription to verify their cylinder values. I asked the five students to note how the objects appeared once they focused the telescope. For this test I used only the 8-inch Meade Schmidt Cassegrain because it was motor-driven. I didn't want the students to be concerned about adjusting the telescope during their observations.

All five saw better with their DioptRx lenses. I asked each — observing separately so they could not influence each other — what he or she saw and how it changed with the DioptRx. Two students were more specific: They saw increased detail when observing the Moon and Saturn at higher magnifications. I continue to collect student data to see if Tele Vue has found that "missing link" for those who report having a poor experience at the eyepiece.

I'm convinced Tele Vue's DioptRx will help those who suffer from astigmatism and hate wearing glasses while observing. At a street price of around $98 per corrector lens, it won't empty their savings. And for those who use only one eye to observe, one corrector lens is sufficient. Imagine that — twice the vision at half the price.

At first, I was skeptical Tele Vue's DioptRx would make a difference. When I used this amazing lens, however, I gasped so loud friends came over to see if something was wrong. I replied, "No, I've just got my sharp vision back. Now, I can throw away these glasses!"

/// SPECIFICATIONS

TELE VUE DIOPTRX

Range: 0.25 to 2.5 diopters in 0.25-diopter steps, in addition to 3.0 and 3.5 diopters
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[t] 845.469.4551
[w] www.televue.com

Learn how one astroimager succeeds in a light-polluted sky.

/// BY JAMES R. FOSTER

Shooting through the light

If you think your night sky is too

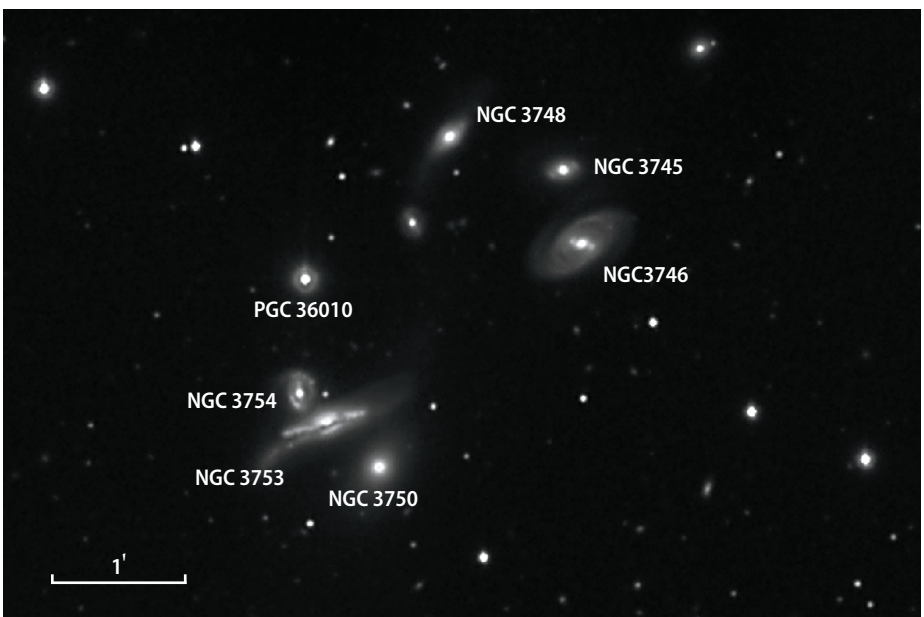
bright for astroimaging, think again. Sophisticated urban-environment astroimaging is now possible with charge-coupled-device (CCD) technology few photographers would have envisioned several years ago. With careful planning, you can produce stunning astroimages or make valuable contributions to cutting-edge astrophysics despite working under intense light pollution.

Astroimagers no longer have to drive to remote dark-sky locations to take stunning images or collect scientific data. Urban astroimaging with state-of-the-art CCD technology and the right filters is a good idea for astroimagers who wish to have all of their equipment near, like the convenience of being at home, and who want to maximize their observing time.

Locations dark and bright

I began capturing celestial images on film in 1987. During those early days, I imaged mostly from Mount Pinos, a dark site about 8,300 feet (2,530 meters) above sea level in Los Angeles County, California. Since moving to downtown Los Angeles in 2002, a mere 300 feet (89m) above sea level, I have had to contend with the challenges of astroimaging from a heavily lighted area through more atmosphere.

Nearly three out of four Americans live in an urban or suburban area, where the night sky is so bright, few things are visible except the Sun, Moon, Jupiter, and Venus. On a clear night, I can see stars slightly dimmer than magnitude 3 at the zenith. However, I've learned how to shoot through the light. Here's how I do it.



COPELAND'S SEPTET is a group of seven closely spaced, 14th- and 15th-magnitude galaxies located in the constellation Leo. Spiral galaxy NGC 3753 is the group's primary galaxy. Foster shot this 10-minute exposure using an SBIG ST-7E CCD camera.

The setup

I use a 13-inch f/7.5 Cassegrain telescope I designed and built with the aid of optician Tom Scott of Scott Optics. The scope sits atop an Astro-Physics AP1200GTO2 mount on a 10-inch-diameter by 4-foot-high cylindrical aluminum pier. Dovetail plates on the scope's top and bottom allow me to attach and remove a finder scope or other imaging scopes. The telescope resides in an 8' by 8' by 5' (2.4m by 2.4m by 1.5m) roll-off-roof observatory on my deck.

The camera, focuser, and everything else in the observatory are powered by a 50-foot extension cord running beneath the deck inside a PVC electric-conduit pipe, to insulate it from dampness and soil rot. I run a control line and a parallel-port line for the CCD cameras, another control line for the focuser, and a serial line for the telescope mount in an adjacent PVC conduit. A single USB-CAT5 extender connects the CCD camera with a computer inside my house. All of these control lines go into a pre-existing, insulated, TV-cable hole that sits next to the main computers. A laptop controls the telescope and imaging equipment.

Assess your sky

Moon phase, atmospheric transparency, and skyglow affect the targets you select to image. A Full Moon will hinder your ability to shoot faint deep-sky targets.

James R. Foster *is an astroimager who resides in Los Angeles. He has worked for the U.S. Army Corps of Engineers for the past 20 years.*

ASTROIMAGER James R. Foster proudly stands next to his astroimaging setup inside his roll-off-roof observatory. Foster uses a variety of techniques to shoot through the light surrounding his Los Angeles home and obtain high-quality astronomical images.

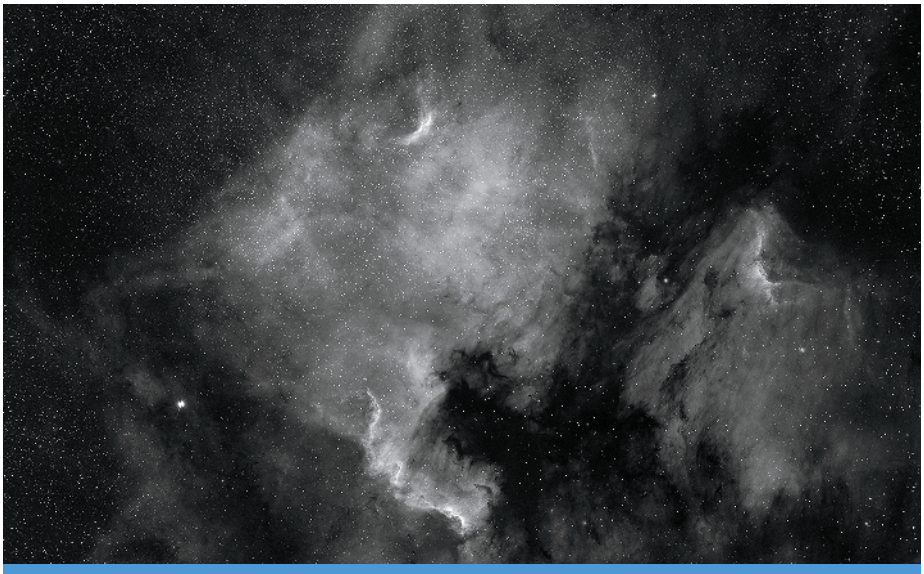
(ALL IMAGES TAKEN BY JAMES R. FOSTER FROM HIS LOS ANGELES HOME UNLESS OTHERWISE NOTED.)

FOSTER'S OBSERVATORY houses a 13-inch Cassegrain telescope with two SBIG CCD cameras on a custom-made pier.

THIS ROLL-OFF-ROOF observatory stands 8′ by 8′ by 5′ (2.4m by 2.4m by 1.5m) and sits on Foster's back deck.

THE TRAPEZIUM cluster of young, hot stars is the brightest region in the Orion Nebula (M42). Foster composed this close-up using luminance (L), red (R), green (G), and blue (B) exposures of 60, 40, 35, and 50 minutes, respectively. He used a 13-inch Cassegrain telescope at f/7.5 and shot the individual visible-light exposures contained in this composite image.

NGC 6888 glows red in this image taken from Mount Pinos, a dark-sky location in Los Angeles County. Foster shot RGB exposures of 63, 63, and 70 minutes, respectively, using an SBIG STL-11000 CCD camera. He combined these exposures with a 347-minute Hα exposure taken from his Los Angeles home to compose this image of the Crescent Nebula.



NGC 7000 AND IC 5067-70, called the North America Nebula (center) and the Pelican Nebula (right), are a striking sight. Foster used a 4-inch Genesis refractor at f/5 and an Hα filter to shoot several 10-minute exposures. The final image combines 17 exposures.

High, thin cirrus clouds and high humidity each diminish atmospheric transparency. Low atmospheric transparency limits imaging to brighter objects, such as any visible planets.

Skyglow, or spectral contamination, is a brightening of the night sky. Artificial lighting is the most common skyglow. Low- and high-pressure sodium, mercury-vapor, metal halide, neon, and incandescent lighting cause a bright orange or bluish dome of light in the sky above brightly lit cities. Skyglow negatively impacts astroimaging results.

THE HORSEHEAD NEBULA (Barnard 33) rises above emission nebula IC 434 in the background, while the Flame Nebula (NGC 2024) sits at the bottom left of the image. Luminance and Hydrogen-alpha (Hα) exposures of 15 and 162 minutes, respectively, were taken with a 10-inch (254mm) Newtonian reflector at f/4.5.

Mercury-vapor lighting (color appears somewhat blue) is the best lighting for astroimaging. It has the smallest spectral footprint of all lighting types, meaning it emits the lowest number of lumens per watt. The spectral components of my local light pollution are in the orange-yellow and green-blue portions of the spectrum, which correspond to high-pressure sodium, mercury-vapor, neon, and incandescent lighting.

I use a deep-sky filter to block mercury-vapor, high- and low-pressure sodium, and neon light commonly emitted by artificial lighting and allow visible light to pass through. An ultra-high-contrast (UHC), narrowband filter allows light from doubly-ionized oxygen (496nm and 591nm) and hydrogen-beta (486nm) light from planetary and emission nebulae to pass through while blocking other wavelengths. An Oxygen III (OIII), narrowband filter allows only light from doubly-ionized oxygen (496nm and 591nm) to pass through.

Calculate your sky's brightness

Once you know your local sources of skyglow, the next step is to measure how bright your night sky is. Measure your local sky's brightness, or Standard Background Flux (SBF), to compute the light-pollution intensity and find your imaging-time limit. The higher your SBF, the shorter the imaging time.

I calculated my local sky's SBF using Johannes Huwe's online SBF Calculator (www.skyobjects.com) and a CCD camera. First, I shot 10-minute exposures 10 times at or near the zenith at a local dark-sky site — for me, that's Mt. Pinos. Then, I shot 10 identical exposures at my Los Angeles home using the same optical system. I took average SBF values for both sites and compared them. The night sky in Los Angeles is almost 16 times brighter than that at Mt. Pinos.

Pretty pictures or solid science?

Astroimaging can fulfill your desire to capture the magnificent beauty of the universe and contribute to the science of astronomy. Either way, narrow-band CCD astroimaging is possible from bright-sky locations. Many well-known astroimagers, including myself, specialize in and frequently shoot from heavily light-polluted areas using Hydrogen-alpha (Hα), Oxygen III (OIII), Sulfur II (SII), Infrared (IR), or other filters.

Use an Hα filter to take beautiful nebula images. Most nebulae emit 90 percent of their light as Hα light (656.28nm). An Hα filter allows only this specific wavelength of light through and filters out light pollution. To obtain detailed nebula shots, I take 10-minute exposures using a 6nm-bandwidth Hα filter with my 13-inch scope.

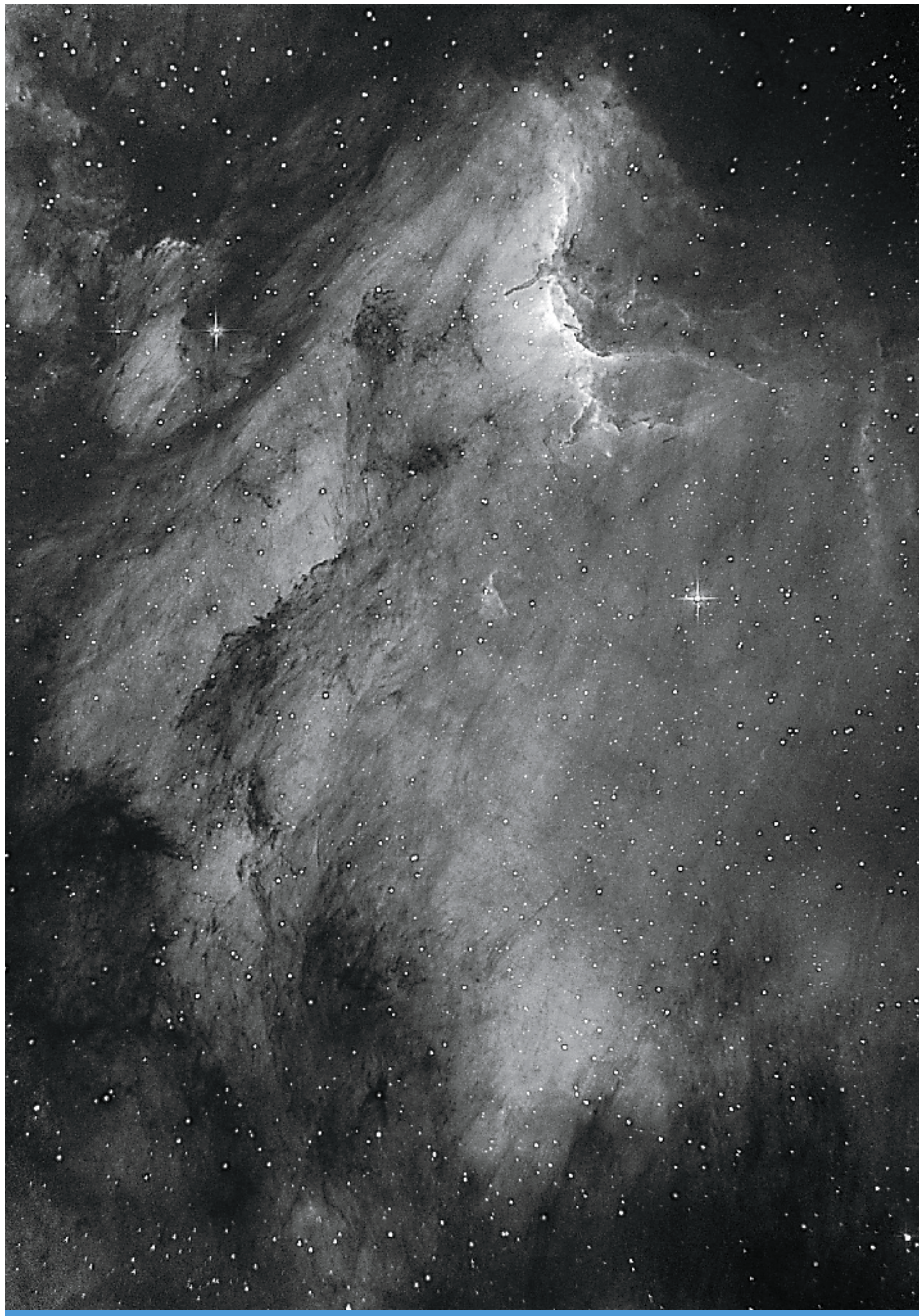
If scientific contribution interests you, try astrometry or photometry. Astrometry involves taking images to refine the positions of asteroids, comets, or other near-Earth objects (NEOs) and precisely measuring their positions relative to nearby stars — those whose locations are well known. One kind of photometry involves taking images of a variable-star field and comparing the magnitudes of nearby standard stars with the variable star in question.

To obtain astrometric data, I take five or more images of an object to compute its orbit. Since NEOs appear mostly starlike, they are not affected much by light pollution. I usually shoot 60- to 180-second exposures at f/6.3 to yield as wide a field as possible. I bin (combining pixels to create larger ones) the CCD pixels to 2x2 (to make a pixel that is 2 times as wide and 4 times the original pixel's area) to get the best signal (low resolution/high sensitivity) in the shortest amount of time. I do this so the object's image doesn't trail much through the star field. Then, using *Astrometrica* software (www.astrometrica.com), I process a set of images to submit to the Minor Planet Center in Cambridge, Massachusetts, for final data analysis and recording. I contributed 767 astrometric measurements of 60 NEOs brighter than 19th magnitude between 2003 and 2005.

For photometry, I take multiple images through photometric visual, or green, filters for 30 minutes or more. Then, I use *MaxImDL*'s photometric-reduction system to reduce the photometric data. The American Association of Variable Star Observers (AAVSO.org) has detailed instructions on conducting photometry with amateur equipment. These data are important because they usually support science teams making simultaneous observations.

I submitted some 2,000 such observations from my urban location between late 2003 and early 2005.

ONLINE EXTRA To see more of James R. Foster's astroimages, visit www.astronomy.com/toc.



THE PELICAN NEBULA (IC 5070) lies some 2,000 light years away in the constellation Cygnus the Swan. Foster used a 10-inch (254mm) Newtonian reflector at f/4.5 and a Hydrogen-alpha (Hα) filter to take a 49-minute exposure of the Pelican. He shot this image from his backyard observatory in downtown Los Angeles.

EQUIPMENT REVIEW

Ease of use and terrific optics place the Stellarvue SV4 high on any observer's want list. /// BY PHIL HARRINGTON

Head of the glass

Today we enjoy a greater variety of telescope designs and levels of sophistication than ever before, but several niches seem to be consistently more popular than others. Among them are 4-inch apochromatic refractors. ☾ Recently, I observed through the 4-inch f/6.4 SV4 apochromatic refractor from Stellarvue Telescopes. At the heart of the SV4 is LOMO's fully multicoated objective. Made with three air-spaced lens elements, including a Super ED center element, the objective suppresses residual chromatic aberration, which would otherwise impact image quality. The advanced design also goes a long way to eliminating astigmatism, coma, spherical aberration, and other optical imperfections.

Stellarvue offers two levels of the SV4. Both feature the same optical components, sliding dew caps, thread-on dust caps, and removable tube sections that let owners add a binocular viewer without an auxiliary focus-compensator lens (more about this innovation later).

The SV4 comes with a single-speed 2" Crayford-style focuser, a 1¼" eyepiece adapter, and a padded aluminum-sided case. The more expensive "deluxe" SV4 includes an exceptional two-speed Crayford-style focuser from Feather Touch (Starlight Instruments), a red-dot unity finder, and a pair of nicely machined aluminum mounting rings.

I tested the standard SV4. It arrived in two well-packed boxes. One box contained the telescope nestled snugly in its padded aluminum carrying case, while the second contained the M6 Stableglide alt-azimuth mount, which is normally sold separately. The quality of the telescope's mechanical design was apparent immediately as I lifted the 22-inch-long (56 centimeters) aluminum tube out of its case.

The only assembly required was to attach the dovetail mounting plate to the telescope's pair of rotating rings and to screw its matching base plate onto the sturdily built M6 mount using the included cap-head screws and Allen wrenches.

The mount's altitude-azimuth base is made from black-anodized aluminum — a finish as durable as it is attractive. Inside the azimuth bearing, a 4.5-inch-diameter (11 cm) Teflon plate lies sandwiched between two machined plates and provides smooth left-right movement. The altitude axis includes two 1-inch (2.5 cm) steel shafts and two sealed needle-bearing units for equally smooth up-and-down motions with no backlash or wobble. In fact, the mount moves a little too freely if the telescope isn't balanced. Tightening the M6's two large hand knobs adds resistance, but balance remains critical.

The M6's unusual double-arm design places the telescope to one side of the tripod, which keeps the telescope from colliding with the tripod when aimed near the zenith. To counterbalance the resultant load, an 8.5-pound (3.9 kilograms) counterweight slides along a 9.5-inch-long (24

Phil Harrington *is a contributing editor of* Astronomy *who loves testing new scopes. His most recent book,* The Illustrated Timeline of the Universe, *coauthored with Richard Sanderson, is published by Sterling Publishing.*

BOTH VERSIONS of the SV4 come safely and securely packed within a padded aluminum case. The case also has room for an optional star diagonal.

IN ADDITION to the standard SV4, Stellarvue makes a binocular-friendly version using a shorter main tube. With this setup, you can use a binoviewer without an optical corrector.

STELLARVUE TELESCOPES' SV4 offers high-quality optics in a small package. Optional accessories include the M6 mount and walnut Stablelock tripod. ALL PHOTOS: *ASTRONOMY*: WILLIAM ZUBACK

THE SV4 uses a two-speed 1¼" standard Crayford focuser. If you own 2" eyepieces, you'll want the SV4 Deluxe, which upgrades the focuser to a 2" Feather Touch Crayford model.

FOR EASY OBSERVING with both eyes, Stellarvue offers an optional binoviewer. This unit comes with a matched set of fully multicoated 23mm 1¼" eyepieces.

cm) steel shaft that threads into the mount opposite the 11-pound (5 kg) telescope. Alternately, the arms can hold two telescopes simultaneously, provided their combined weight doesn't exceed the mount's capacity of 30 pounds (14 kg). An adjustable tripod made from stained and sealed walnut supports the M6. A matching wooden accessory tray that attaches between the legs can hold six eyepieces and makes the tripod more rigid.

Over the last few years, the popularity of binocular eyepiece viewers has grown. Unfortunately, most telescope focusers do not have enough range to accommodate the 4-inch path that light must follow inside a typical viewer. To bring objects into focus, observers often insert either a Barlow lens or a specially designed compensator lens between the telescope and binoviewer. Although these work, each increases the system's magnification, and, therefore, narrows the field of view.

To avoid this, the SV4's tube separates into two pieces. Keep the 4-inch-long threaded extension tube in place, and images will focus perfectly for conventional viewing using a star diagonal and single eyepiece. Remove the extension tube to switch to binoviewing mode, and the shortened assembly focuses correctly with a binoviewer in place. It sounds simple, but, unless the threaded extension is engineered precisely, optical collimation will be lost. Well aware of the consequences, Stellarvue uses Computer Numerically Controlled (CNC) machining equipment to ensure tight tolerances.

Beneath the sky

Stellarvue puts a lot of effort into the details, but how well does the SV4 actually work? This past winter, I put it through its paces by viewing the Moon, several planets, and several deep-sky objects. Using the scope in temperatures down to 10° Fahrenheit (–12° Celsius) also allowed me to see if the mechanics would work as smoothly in the cold as they did in my living room.

As luck would have it, the SV4 arrived on a clear, cold February day. Setup went quickly, giving me a chance to take the scope on its inaugural flight that night. I always begin by performing a star test, the tell-all check that compares images of a star seen slightly inside of focus versus its appearance slightly outside of focus. Both out-of-focus images were identical, proving the SV4's optics are superb.

Of course, no one buys a telescope just for testing. Over the course of the next week, as the Moon passed from crescent to First Quarter to gibbous, I followed the progress of the lunar terminator (the day/night boundary) as it swept eastward. My favorite phase, the 8-day-old Moon, is highlighted by the emergence of Clavius Crater from the lunar night. This event seen through the SV4 was made even more striking by the blackness of the shadows and the razor sharpness of Clavius' rim.

The SV4's overall image contrast surpassed the milky-gray shadows seen with lesser instruments that suffer from internal light scatter. The SV4 doesn't have this problem thanks to three baffles and light-dampening ridges in the extension tube and focuser. The tube's inside also is textured to reduce reflection and coated with three coats of flat black paint. The only deviation from perfection (and this is me being super-critical) was a slight yellowish edge to the bright lunar limb, which indicates a minor amount of residual chromatic aberration. But the scope's overall suppression of false color was terrific.

FOR PUBLIC or "paired" observing, the M6 mount can accommodate two telescopes (one on each side of the horizontal black bar), or one telescope and a counterweight.

The following night, steady atmospheric conditions let me watch sunrise over Sinus Iridium at 232x. The seeing was so steady, I spotted some of the craterlets on the dark floor of the walled plain Plato to the west. Spotting these tiny features, each measuring no more than 1.4 miles (2.2 kilometers) across, is one of the great challenges facing lunar observers. Plato's lava-covered floor usually appears featureless.

Next, two planets awaited my visit. Mars, although well past its prime 2005 opposition, still sat high in the west. At 232x, I viewed the South Polar Cap and Syrtis Major easily. Saturn, riding high in the east, showed a level of definition that betrayed the SV4's small aperture. The rings were remarkably crisp, with the Cassini Division appearing like a sharpened pencil point drawn across a white sheet of paper. The subtle gray Crepe, or C, ring also was evident, silhouetted against the yellowish planetary disk.

Once the Moon left the sky, I turned the SV4 toward some of my favorite deep-sky objects. With a 22mm eyepiece (29.5x), the SV4 squeezes more than 2° into view, more than enough to enjoy the sparkling view of the entire Pleiades cluster (M45) at once. Scanning southward to Orion, the hunter's sword easily fit into the same field.

Switching eyepieces and increasing magnification back to 232x, I was pleasantly surprised to see all six members of the Trapezium system (Theta^1 [θ^1] Orionis) inside the Orion Nebula (M42). According to my observing notes, this was the first time I had seen all six through such a small aperture. Moving into the early morning, I also resolved the challenging greenish companion of the brilliant red giant star Antares (Alpha [α] Scorpii), a great test for a 4-inch scope. Spotting all four stars that make up the Double Double (Epsilon [ε] Lyrae) in Lyra was a snap.

Unlike some telescope mounts, the SV4's lubrication was unaffected by temperature. As I tested the telescope and mount throughout the cold winter nights, the SV4 and M6 worked just as smoothly as they did inside my warm house. Visible vibrations settled out in a matter of 2 or 3 seconds after I rapped the telescope with the palm of my hand, a quite acceptable damp-down time.

THE SV4'S primary optic — a 4-inch apochromatic triplet lens with a focal ratio of 6.4 — sits at the tube's front. The standard tube-assembly color is White Pearl. Stellarvue also offers Stardust Blue as an option.

A stellar company

Stellarvue is based in Auburn, California, and is owned by amateur astronomer Vic Maris. Since opening its doors in 1998, Stellarvue has become known as a reliable source of achromatic and apochromatic refractors. Stellarvue instruments range in size from 2.6 to 4 inches. I tested Stellarvue's 3.1-inch f/9 SV80D achromat as part of my survey of small achromatic refractors in the October 2002 issue, and it proved to be the best in class by a wide margin. Would the SV4 continue that tradition?

Part of Stellarvue's overall success is due to Maris' involvement with every instrument that carries his company's name. Maris marries optical components designed and fabricated by LOMO PLC in St. Petersburg, Russia, with tube assemblies crafted in his Auburn factory. Even though LOMO's consistency is excellent, Stellarvue confirms the optical quality of each objective 3 times. First, a technician tests each with an interferometer. Another test occurs on an optical bench after the objective assembly has been installed into its tube. Finally, Maris star tests each telescope personally to certify the instrument is one he would enjoy using.

The SV4 is one of the finest apochromatics sold today. If you purchase this scope, it will give you years of satisfaction, whether this means traveling to your backyard or flying halfway around the world.

/// SPECIFICATIONS

STELLARVUE SV4

Type: Apochromatic refractor
Lens diameter: 4 inches (100 millimeters)
Focal ratio: f/6.4
Focal length: 650mm
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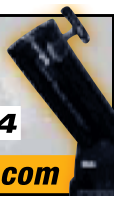

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The All Arizona Star Party lacks the typical roster of activities, such as workshops, contests, and lectures, but makes up for it with superior observing. The event's rural location near Arizona City is under a clear, dark sky and provides low horizons with no imposing flora,

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ALL ARIZONA STAR PARTY attendees ready their equipment for a night of observing and astroimaging while waiting for darkness to fall.

so superior viewing is the norm. Participants will need to supply essentials, such as water and electricity.

For more information, visit www.eastvalleyastronomy.org/aasp.htm.

SEPTEMBER 26–OCTOBER 1

Northern Prairie Starfest

Black Nugget Lake Campground, Tofield, Alberta. Activities will include observing, canoeing, and fishing. The site is located on a fall migration flyway and offers exceptional birding opportunities. For more information, visit edmontonrasc.com/nps.html.

SEPTEMBER 28–OCTOBER 1

Prairie Skies Star Party

Camp Shaw-Waw-Nas-See, near Kankakee, Illinois. Chicago is nearby, but this site's location will provide quality viewing relative to the region. For more information, visit www.prairieskies.org.

SEPTEMBER 30

Virginia Association of Astronomy Societies Convention

Randolph-Macon College, Ashland, Virginia. This event will feature speakers, displays, prizes, and vendors. For more information, visit www.richastro.org.

SEPTEMBER 30–OCTOBER 1

Whirlpool Star Party

Dooley's Hotel, Birr, Ireland. This star party allows attendees to gather under the shadow of the "Leviathan of Parsonstown," the 72-inch scope still housed at Birr Castle. For more information, visit www.geocities.com/shannonsideac.

OCTOBER 6–8

CCD Workshop

Cincinnati Observatory Center, Cincinnati. Learn how to produce stunning images of deep-sky objects from Adam Block, founder of Kitt Peak National Observatory's Advanced Observing Program. The theme for the workshop is "Making Each Pixel Count." For more information, e-mail Adam Block at ngc1535@caelumobservatory.com; web site, www.caelumobservatory.com/cocworkshop.shtml.

OCTOBER 16–22

Peach State Star Gaze

White Water Express High Adventure Camp, Ducktown, Tennessee. The Atlanta Astronomy Club has created observing challenges for attendees regardless of equipment, experience, or ability. This event will include workshops on topics ranging from imaging to star-hopping to sky-sketching. For more information, visit www.atlantaastronomy.org.

OCTOBER 17–22

Southern New Mexico Star Party

City of Rocks State Park, near Faywood, New Mexico. Hosted by the National Public Observatory, this event is held at an elevation of about 5,000 feet (1,525 meters), ensuring dark skies. For more information, visit www.astro-npo.org.

OCTOBER 18–22

Deep South Regional Star Gaze

Camp Ruth Lee, Norwood, Louisiana. This new location will provide a darker sky than the previous site and has amenities situated near the scope field. The Star Gaze will be able to accommodate RVs and campers. For more information, visit www.stargazing.net/dsrsg.

OCTOBER 18–21

Eldorado Star Party

X-Bar Ranch, near Eldorado, Texas. Co-sponsored by the Texas Star Party and clubs throughout the state, this event is held under a dark sky on a 7,100-acre protected site. For more information, visit www.texasstarparty.org.

OCTOBER 20–21

Custer Institute's Annual Astronomy Jamboree

Custer Institute, Southold, New York. The institute will use the weekend to celebrate its new 22-foot Ash Dome and 16-inch Meade LX200. Activities will include observing, live music, children's events, and a swap meet. For more information, visit www.custerobservatory.org.

OCTOBER 20–22

Stella Della Valley Starfest

Camp Onas, near Ottsville, Pennsylvania. This gathering will feature observing, workshops, guest speakers, a swap meet, and vendors. For more information, visit www.bma2.org.

OCTOBER 21–23

Hidden Hollow Weekend

Warren Rupp Observatory, Mansfield, Ohio. This star party will feature observing, lectures, and workshops. The facility houses a 31-inch reflector. For more information, visit www.wro.org.

OCTOBER 27–29

Volunteer State Star Party

Von Braun Astronomical Society dark-sky site, near Hohenwald, Tennessee. There won't be any organized daytime activities; observing is the main focus of this star party. For more information, visit www.vbas.org/mlo.cfm.

CONTACT INFORMATION

Please submit club announcements 5 months in advance to Coming Events, *Astronomy*, P. O. Box 1612, Waukesha, WI 53187, or jmcgovern@astronomy.com. Also use this e-mail address to submit your events for our online calendar.

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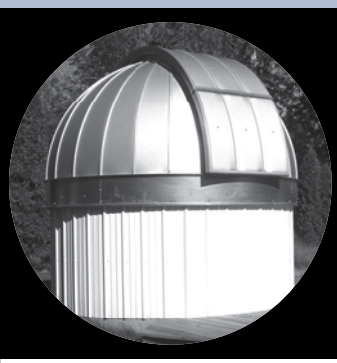

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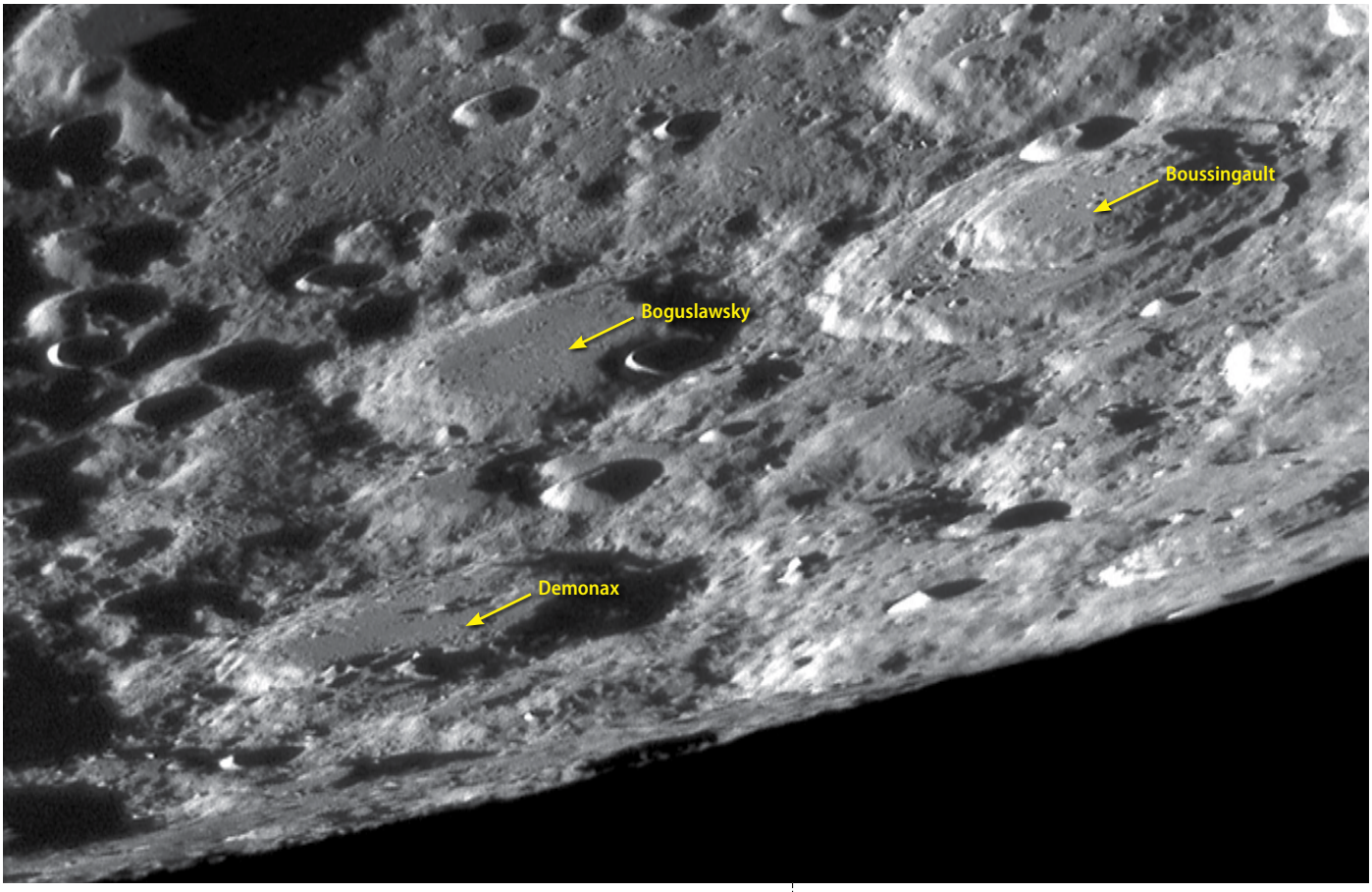


LUNAR OBSERVING

Hidden lunar treasures

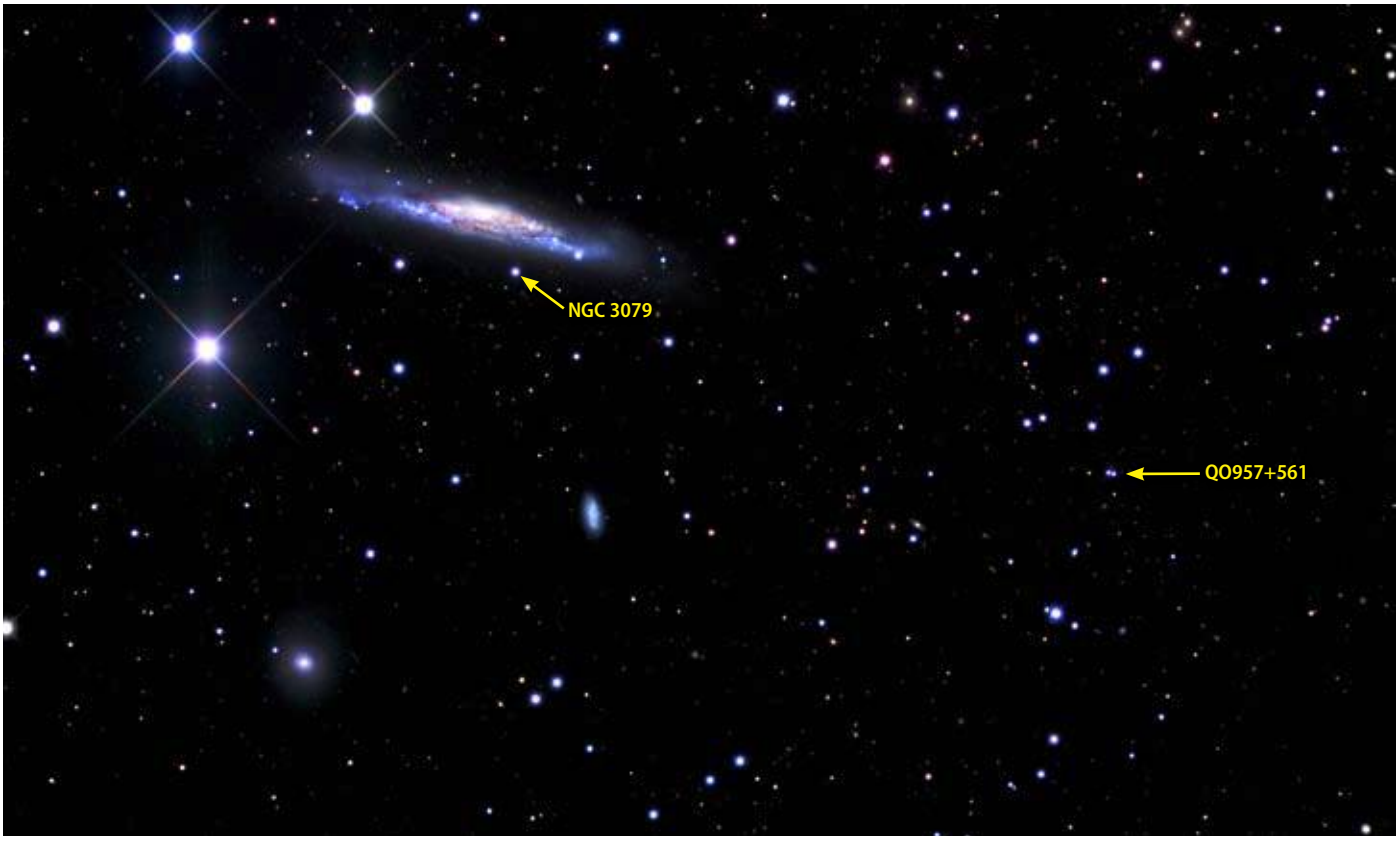
The Moon's south polar region offers observers both rewards and challenges. This densely cratered region sometimes makes identifying features tricky. Adding to the difficulty is the fact that we see the craters along the Moon's edge at a steep angle. Here, we see an area east of the Moon's south pole.

Probably the first feature you'll notice through a telescope at around 100x is Boussingault Crater, which measures 81 miles (131 kilometers) across. Within Boussingault lies another crater — Boussingault A. Together, these features give the appearance of a double-walled crater. A bit to the west, Boguslawsky Crater looks totally different. This 60-mile-wide (97 km) crater has a floor that lava flooded and filled long ago. North is up in this image.

▲ **LUNAR SOUTH POLE** (12-inch Lazzarotti Optics Gladio 315 Dall-Kirkham telescope at f/25, Lumenera Infinity 2–1 CCD camera; imager chose the best 260 of 2,000 images — each a 0.055-second exposure, taken April 4, 2006, starting at 18h41m UT, from Massa, Italy) /// **PAOLO R. LAZZAROTTI, MASSA, ITALY**

► **SPIRAL GALAXY** NGC 3079 in Ursa Major is not this image's highlight. What looks like a double star to the right of center — Q0957+561 — is noteworthy as the first gravitationally lensed quasar discovered, in 1979. (20-inch and 12.5-inch RC Optical Systems Ritchey-Chrétien telescopes, SBIG STL-11000 CCD camera, LRGB image with exposures of 7, 2, 2, and 2 hours, respectively) /// **ROBERT GENDLER, AVON, CONNECTICUT**

PLANETARY NEBULA ABELL 24 in Canis Minor defines the words "difficult visual observation." To see this object, you'll need at least a 20-inch telescope, an OIII filter, a dark observing site, and plenty of patience. A CCD camera, however, easily captures it, revealing a red cloud with a magnitude 17.1 central star. (12.5-inch homemade Newtonian reflector at f/5, SBIG ST-10XME CCD camera, LRGB image with exposures of 60, 20, 20, and 20 minutes, respectively) /// **CHRIS SCHUR, PAYSON, ARIZONA**



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THE YOUNG MOON and Mercury make a nice pair after sunset. At the time of this image, the Moon was only 47 hours past new. Mercury sat 11.5° west of the Moon and shone at magnitude 0.8. (Canon EOS 20D digital SLR, Tamron 70–300mm lens set approximately at 150mm, ISO 200, 0.4-second exposure, taken March 1, 2006, at 6:26 P.M. EST) /// **RALPH L. BOUGHER, BERLIN, NEW JERSEY**

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Veil image courtesy of Robert Gendler.
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SPECIAL REPORT

Atlas of extrasolar planets

The worlds beyond our solar system show a rich diversity no one suspected. /// BY RICHARD TALCOTT; ILLUSTRATIONS BY LYNETTE COOK

MASSIVE gas giants dominate the planets found so far.

In 1990, most astronomers were confident what other planetary systems would look like. Assuming distant solar systems would resemble our own — the only example then known — scientists expected to find small, rocky worlds orbiting close to their parent stars and big, gaseous planets located far away. The stars themselves wouldn't necessarily be solar clones, but they would be stable and live long enough for planets to accrete from a circumstellar disk of gas and dust.

The coffin for that idea was constructed in 1991, when American radio astronomers Aleksander Wolszczan and Dale Frail discovered the first extrasolar planets — circling a rapidly spinning pulsar. Like all pulsars, PSR B1257+12 was born when a short-lived massive star exhausted its nuclear fuel and exploded. Any existing planets either would have been destroyed by the supernova explosion or hurled into interstellar space as the parent star expelled most of its mass and lost its gravitational hold. So, the planets found by Wolszczan and Frail must have formed in the supernova's aftermath. Certainly, this was a scenario no astronomer predicted.

The final nails in the coffin came 4 years later. First, Swiss astronomers Michel Mayor and Didier Queloz discovered a Jupiter-size planet circling a normal star, 51 Pegasi. But this massive world lies only 1/100 the distance from its star as Jupiter is from the Sun and completes one orbit every 4.2 days.

Next, American astronomers Geoff Marcy and Paul Butler announced two more planets, one each around the Sun-like stars 70 Virginis and 47 Ursae Majoris. Both worlds contain significantly more mass than Jupiter and orbit closer to their parent stars than Jupiter's distance from the Sun. These three "hot Jupiters" once again proved Mother Nature has more up her sleeve than scientists had imagined.

In the decade since these initial discoveries, approximately 200 more planets have been found. As observing techniques improved and searches stretched over longer periods, many planets with lower masses, and others with bigger orbits, have turned up.

Still, astronomers have yet to find a planet or system they would dare call "normal" — or one that comes close to matching our home system. We live in a universe of captivating exoplanets — a universe that promises to grow more intriguing in the years ahead. ◘

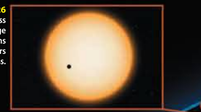
Richard Talcott *is a senior editor of* Astronomy. *Artist* **Lynette Cook** *illustrated* Infinite Worlds: An Illustrated Voyage to Planets Beyond the Sun *(University of California Press, 2005).*

VOLCANIC ERUPTIONS likely will create atmospheres around some rocky planets.

▶ 47 URSAE MAJORIS
This system holds two planets with masses and orbits not too different from Jupiter's.

▶ TAU BOÖTIS
This big planet can retain its atmosphere despite lying 4 million miles from its star.

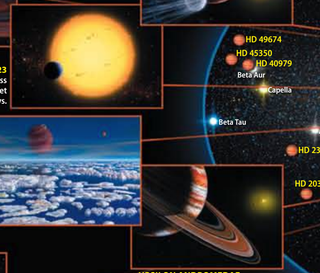
▶ RHO CORONAE BOREALIS
This Jupiter-mass world completes a circuit of its Sun-like star in 40 days.



▶ HD 149026
This Saturn-mass planet has a huge core that contains three-quarters of its mass.

▼ HD 177830
Orbiting at Earth's distance from the Sun, this gas giant (and any moon) lies in its star's habitable zone.

▶ 16 CYGNI B
This planet orbits one of two Sun-like stars that form a wide binary system.



▶ HD 187123
This "hot Jupiter" with half the mass of our solar system's biggest planet circles its star in 3.1 days.

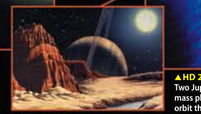
▶ HD 168443
Tidal forces could melt ice on a possible moon of this massive planet or brown dwarf.

▲ UPSILON ANDROMEDAE
This was the first multi-planet system found around a normal star.

▲ HD 195019
This gas giant weighs 3.4 Jupiters and orbits its Sun-like star in 18 days.

▶ 51 PEGASI
The first planet found around a Sun-like star was this "hot Jupiter" — a gas giant near its parent star.

▲ HD 209458
The first planet found transiting its parent star, it's also the first to have its atmosphere directly detected.



▲ HD 16141
A possible moon's arid landscape attests to this gas giant's proximity to its Sun-like star.

▲ HD 217107
Two Jupiter-mass planets orbit this solar-mass star; one (seen here) in 7 days, the other in 9 years.

▲ HD 222582
This planet's orbit would range from innermost Mercury to the asteroid belt.

▲ GLIESE 876
This was the first planetary system found around a red dwarf star. Its smallest planet weighs just 7 Earths.

▲ OGLE235-MOA53
This Jupiter-size world was the first planet found through microlensing.

▲ OGLE-05-169L
This Uranus-mass planet could be either rocky or gaseous.

◀ OGLE-05-390L
This planet of rock and/or ice weighs 5 Earths, and takes 10 years to orbit its M-dwarf star.

◀ IOTA HOROLOGII
This planet has an earthlike orbit, but its star appears younger and more active than the Sun.

◀ EPSILON ERIDANI
The closest planet beyond our solar system lies 10.5 light-years from Earth.

▲ HD 82943
Two giant planets occupy this system, but the lithium-rich star probably has swallowed others.

▲ HD 38529
It takes 6 years for this gas giant to orbit its distant sun, which harbors another, closer-in planet.

◀ PSR B1257+12
The first exoplanets discovered, these three worlds orbit an energetic pulsar.

◀ PSR B1620–26
The oldest planet known (13 billion years), this world lies in the globular star cluster M4.

◀ HD 114762
This object weighs at least 11 Jupiters and might be a brown dwarf instead of a planet.

◀ 70 VIRGINIS
The gas-giant planet in the background weighs at least 7 Jupiters.

◀ 55 CANCRI
This four-planet system more closely resembles our solar system than any other known.

▲ HD 46375
This Saturn-mass planet orbits its orange sun in just 3 days.

HD 114762 HD 108874 Tau Boo PSR B1257+12 70 Vir HD 106252 Gliese 436 Arcturus Epsilon UMa Eta UMa 47 UMa HD 118203 HD 128311 HD 114783 HD 102195 HD 99492 HD 130322 Spica HD 89744 Alpha UMa Iota Dra 14 Her Rho CrB HD 149026 HD 89307 HD 88133 Regulus HD 92788 HD 136118 BD –103166 HD 81040 HD 80606 HD 104985 Gliese 581 HD 86081 55 Cnc HD 68988 HD 150706 HD 149143 HD 134987 HD 114729 Alphard Polaris HD 141937 HD 117207 HD 114386 HD 82943 HD 74156 Pollux HD 33564 Vega HD 109749 2M1207 HD 93083 HD 72659 Castor HD 49674 TrES-1 PSR B1620–26 GQ Lup HD 117618 HD 59686 HD 45350 Gamma Cep Antares Procyon HD 40979 HD 178911B 16 Cyg B HD 147513 HD 121504 Gamma Cru HD 83443 HD 73256 HD 50554 Beta Aur HD 177830 HD 188753A HD 187123 HD 168443 HD 330075 Beta Cru HD 101930 HD 75289 Gamma Gem Capella Deneb OGLE-TR-10 Acrux HD 102717 HD 73526 HD 46375 Gliese 777A HD 188015 HD 168746 Alpha Cen OGLE-TR-56 Shaula HD 108147 OGLE-TR-113 Beta Tau HD 190228 HD 183263 OGLE-TR-111 HD 142415 HD 70642 HD S2265 Alpha Per HD 189733 OGLE-05-169L Theta Sco Delta Vel Delta CMa HD 37124 Altair HD 169830 FU Tau(A) Gamma Vel Sirius Betelgeuse HD 23596 HD 195019 Epsilon Sgr HD 154857 HD 111232 HD 76700 Adhara HD 38529 HD 37605 Mu Ara Epsilon Car Zeta Ori Upsilon And HD 196885 Sigma Sgr Alpha TrA Beta Car HD 50499 Beta CMa Bellatrix HD 20367 HD 179949 HD 65216 HD 47536 HD 34445 HD 192263 HD 142022 Epsilon Ori HD 13189 SCR 1845 HD 63454 Canopus HD 33636 Aldebaran HD 209458 HD 187085 HD 39091 AB Pic HD 41004A Rigel HD 12661 HD 8574 51 Peg Alpha Pav HD 212301 Gliese 3021 HD 33283 HD 28185 Hamal HD 196050 HD 27894 HD 30177 HD 10697 HD 3651 HD 202206 HD 216437 HD 27442 HD 19994 HD 4203 HD 210277 Epsilon Eri HD 16141 HD 208487 HD 4308 HD 11977 HD 23079 HD 217107 Gliese 876 Alpha Gru HD 213240 Achernar HD 20782 HD 11964 HD 222582 91 Aqr Fomalhaut Tau' Gru Iota Hor HD 2039 HD 10647 Gliese 86 HD 2638 HD 216770 HD 142 HD 224693 HD 4208 HD 6434

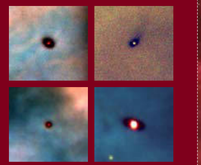
Worlds upon worlds

Astronomers have discovered 200 planets orbiting stars other than the Sun. The 164 systems depicted here contain all the planets known as of July 2006, but you can count on many more turning up in the coming months and years. The map shows the entire sky as seen from Earth. It is plotted in galactic coordinates, with north up and the Milky Way's disk running horizontally through the center. This projection places constellations in unfamiliar locations, so the map plots the 50 brightest stars to help you find your bearings.

WORLDS of rock and ice have started to turn up, a likely harbinger of things to come.

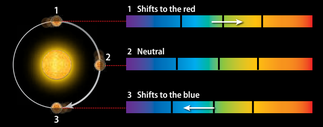
THE ORION NEBULA (M42) glows with radiation released by warm dust in this Spitzer Space Telescope image. Hot young stars in the nebula heat the dust, which forms the raw material for stars and planets yet to develop. NASA/JPL-CALTECH/T. MEGEATH (UNIV. OF TOLEDO, OHIO)

STARS AND GAS dominate the Orion Nebula (M42) in visible light. Stellar winds and ultraviolet radiation can initiate the collapse of new stars with possible planetary systems. NASA/ESA/STScI



PROTOPLANETARY DISKS abound in M42. These disks are rich in gas and dust and likely will coalesce into planetary systems. The reddish glow seen at each disk's center is a newborn star roughly 1 million years old. NASA/ESA/STScI

Detecting new worlds

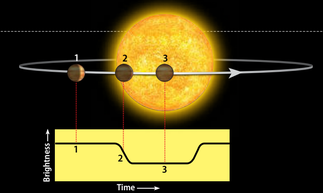


Radial-velocity method

A planet's gravity tugs on its parent star, inducing a wobble in the star's motion. As the star moves closer to Earth, the star's spectral lines shift toward the blue; as the star moves away, the lines shift to the red. These changes allow astronomers to deduce a planet's minimum mass. A variation on this technique — in which a planet alters the timing of a pulsar's signal — has led to the discovery of four planets.

Pros
This is now the leading method — about 90 percent of known exoplanets were found with this technique. It's great at finding heavy planets, which cause bigger changes in radial velocity.

Cons
This method yields only a minimum mass unless astronomers can determine the planet's orbital inclination. Observations must stretch over a long period to find planets in large orbits.

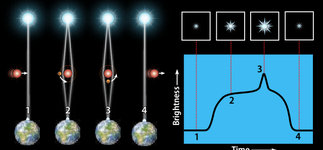


Transit method

If a planet's orbital plane lies along or near our line of sight, the planet will pass in front of the star once each orbit. The planet's black disk causes a small dip in the star's brightness. If the dips occur regularly and produce the same dimming each time, and the star shows no sign of being a periodic variable, the culprit should be a planet. Radial-velocity measurements can confirm the planet's existence.

Pros
Because the orbital inclination is known, astronomers can use radial-velocity measurements to calculate the planet's exact mass.

Cons
Only a small fraction of all planets transit their parent star's disk, because most planets don't orbit along our line of sight.

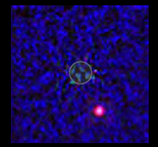


Microlensing method

If a star or planet passes in front of a more distant star, general relativity says the intervening object's gravity will act as a lens, causing the distant star to brighten. Using robotic telescopes, scientists monitor a large number of background stars, looking for microlensing events. A smooth rise and fall in brightness indicates a dim star as the intervening culprit; a blip on a smooth light curve signifies an orbiting planet.

Pros
This method is capable of finding Earth-mass planets with existing technology.

Cons
The microlensing events result from chance alignments, so they can never repeat.



A POSSIBLE PLANET orbits the brown dwarf 2M1207. In this Hubble Space Telescope image, the brown dwarf's light has been subtracted to reveal the companion, which has a minimum mass of 5 Jupiters. NASA/ESA/G. SCHNEIDER (STEWARD OBSERVATORY), ET AL.

Direct-imaging method

As the name implies, this technique requires taking a planet's image. Because a planet shines by reflecting starlight (or emitting its own infrared radiation), it pales in comparison to its parent star. Viewing a planet in a star's glare is a little like seeing a firefly next to a powerful lighthouse beacon. Still, big telescopes on the ground and in space have found a few promising planet candidates.

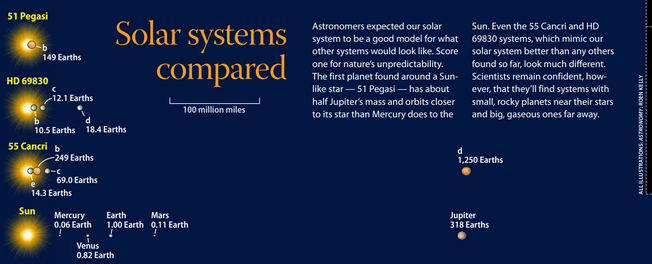
Pros
A detailed spectrum of the planet can reveal its physical characteristics.

Cons
In most cases, the planet turns up through luck — on an image taken for another purpose.

ALL ILLUSTRATIONS: ASTRONOMY: ROEN KELLY

Solar systems compared

Astronomers expected our solar system to be a good model for what other systems would look like. Score one for nature's unpredictability. The first planet found around a Sun-like star — 51 Pegasi — has about half Jupiter's mass and orbits closer to its star than Mercury does to the Sun. Even the 55 Cancri and HD 69830 systems, which mimic our solar system better than any others found so far, look much different. Scientists remain confident, however, that they'll find systems with small, rocky planets near their stars and big, gaseous ones far away.



Road map to other worlds

The Milky Way's 200 (and counting) exoplanets offer astronomers a bewildering array of alien worlds.

/// BY RICHARD TALCOTT

The raw material for making planets pervades our galaxy. Need a gas-giant planet like Jupiter? The rich stores of hydrogen and helium created in the immediate aftermath of the Big Bang will fill the need. How about a rocky planet like Earth? The carbon, silicon, and other heavy elements forged in stars are now spread throughout the galaxy's disk.

Converting these raw elements into planets also seems to be a common process. In the great star-forming factories that dot the galaxy's spiral arms, astronomers see dark disks of gas and dust surrounding many fledgling stars. Although theorists don't have all the nuances figured out, all agree collisions within such disks gradually build planet-size bodies.

Finding extrasolar planets proved harder than most scientists expected. The first detections came in the 1990s, after decades of false starts and "discoveries."

Then the floodgates opened. Better techniques and more accurate observations have found planets in more than 5 percent of the stars studied. And scientists expect that number to climb above 10 percent by the time all is said and done.

So far, most of the planets discovered have been behemoths with masses in the range of Jupiter and Saturn — if not bigger. But in the past couple of years, a number of planets more similar to Uranus and Neptune's size have turned up. With the advent of dedicated space missions in the next several years, the holy grail of planet discoveries — an Earth-size world — should make its first appearance. ■

/// STARS WITH MORE THAN ONE PLANET

Name	Number of known planets	Highest mass (Jupiters)	Lowest mass (Jupiters)
55 Cancri	4	3.92	0.045
PSR 1257+12	3	0.0135	0.00006
Gliese 876	3	1.935	0.023
HD 69830	3	0.058	0.033
Mu Arae	3	3.1	0.044
HD 37124	3	0.66	0.60
Upsilon Andromedae	3	3.75	0.69
Gliese 777A	2	1.502	0.057
47 Ursae Majoris	2	2.54	0.76
HD 38529	2	12.7	0.78
HD 108874	2	1.36	1.018
HD 217107	2	2.1	1.37
HD 12661	2	2.3	1.57
HD 82943	2	2.01	1.75
HD 74156	2	6.17	1.86
HD 128311	2	3.21	2.18
HD 202206	2	17.4	2.44
HD 73526	2	2.9	2.5
HD 169830	2	4.04	2.88
HD 168443	2	17.1	7.2

/// PLANETS POSSIBLY SMALLER THAN NEPTUNE

Name	Mass (Neptunes)	Period (days)	Orbital radius (astronomical units)
PSR 1257+12 b	0.001	25.262	0.19
PSR 1257+12 d	0.227	98.2114	0.46
PSR 1257+12 c	0.251	66.5419	0.36
OGLE-05-390L b	0.315	3,500	2.1
Gliese 876 d	0.426	1.938	0.021
HD 69830 b	0.612	8.667	0.079
HD 69830 c	0.704	31.56	0.186
OGLE-05-169L b	0.741	3,300	2.8
Mu Arae d	0.816	9.55	0.09
55 Cancri e	0.834	2.81	0.038
HD 4308 b	0.871	15.56	0.114

/// BRIGHT STARS WITH PLANETS

Name	Constellation	Magnitude	Number of known planets
Gamma Cephei	Cepheus	3.23	1
Iota Draconis	Draco	3.31	1
Epsilon Eridani	Eridanus	3.73	1
Upsilon Andromedae	Andromeda	4.09	3
91 Aquarii	Aquarius	4.21	1
Tau Boötis	Boötes	4.50	1
70 Virginis	Virgo	5.00	1
HD 19994	Cetus	5.06	1
47 Ursae Majoris	Ursa Major	5.10	2
Mu Arae	Ara	5.15	3
Rho Coronae Borealis	Corona Borealis	5.40	1

Planet-hunting spacecraft

COROT
Scheduled for launch in October 2006, the French-led COROT (COnvection, ROtation and planetary Transits) mission will search for planets using the transit method. The 12-inch (30cm) space telescope will hunt for rocky planets with several times Earth's mass, and mission scientists expect to find between 10 and 40 of them during the 2.5-year mission. CNES

Kepler
NASA's Kepler mission will monitor 100,000 stars for at least 4 years, beginning in 2008. Using the transit method, Kepler's 37-inch (95cm) telescope will search for Earth-size planets. Scientists expect the mission to find about 50 of them, along with hundreds of larger planets. Kepler will also determine the planets' orbits to see how many might be habitable. NASA

SIM PlanetQuest
NASA hopes to launch SIM PlanetQuest — a mission designed to detect earthlike planets around other stars — around 2015. With two telescopes working together, the spacecraft will search the nearest 250 stars looking for other Earths and a few thousand stars looking for Neptune-mass planets. SIM PlanetQuest will find planets by measuring tiny wobbles in a star's position. NASA

Darwin
The European Space Agency plans to launch Darwin around 2015. It will search for terrestrial planets in the habitable zones of stars within 80 light-years of Earth. Then it will study those planets' atmospheres to look for gases that point to the possibility of life and image the planets at high resolution. Darwin will use a flotilla of telescopes, each 3 to 4 meters in diameter. ESA

Terrestrial Planet Finder
Funding for NASA's Terrestrial Planet Finder (TPF) looks tenuous, at best. TPF would consist of two complementary observatories, a visible-light coronagraph to block a parent star's light and an infrared interferometer (shown here). TPF would find and characterize terrestrial planets in the habitable zones of stars and assess those worlds' ability to support life. NASA

For a complete list of all exoplanets known to date, visit www.astronomy.com

NOTABLE EXTRASOLAR PLANETS

FIRST EXOPLANETS DISCOVERED
PSR 1257+12 b, c, and d (1991)

FIRST EXOPLANET DISCOVERED AROUND A NORMAL STAR
51 Pegasi b (1995)

FIRST PLANET DISCOVERED ORBITING A BINARY
PSR B1620–26 b (1993)

FIRST PLANET DISCOVERED IN A STAR CLUSTER
PSR B1620–26 b (1993; globular cluster M4)

STAR WITH MOST KNOWN EXOPLANETS
55 Cancri (4)

CLOSEST EXOPLANET TO EARTH
Epsilon Eridani b (10.5 light-years)

FARTHEST PLANET FROM EARTH
OGLE-05-390L b (21,000 light-years)

SHORTEST-PERIOD EXOPLANET
OGLE-TR-56 b (1.212 days)

LONGEST-PERIOD EXOPLANET
OGLE235-MOA53 b (12.9 years)

LIGHTEST EXOPLANET
PSR 1257+12 b (0.02 Earth)

LARGEST EXOPLANET
HD 209458 b (1.32 Jupiter diameters)

OLDEST PLANET
PSR B1620–26 b (12.7 billion years)

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